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IMPACT OF HYDROLOGIC MODIFICATIONS ON WATER QUALITY

MITRE CORPORATION

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ENVIRONMENTAL PROTECTION AGENCY

APRIL 1975

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This report describes the scope and magnitude of water pollution problems caused by hydrologic modifications (dams, impoundments, channelization, in-water construction, out-of-water construction, and dredging). Types of pollutants released by each class of hydrologic modification are identified, and quantitative estimates are made of the amount of the major pollutant--sediment--that enters the Nation's surface waters as a result of highway and urban construction.

Methods for controlling the release of pollutants from hydrologic modification activities are described, and the effectiveness of sediment control measures is estimated.

Two "loading functions" are developed for predicting the quantities of sediment released from construction operations of given magnitude and location. These functions are based on measurements of sediment yields & other parameters at 10 construction sites. The accuracy and limitations of the functions are analyzed.

Measurement data from all classes of hydrologic modifications are reported in the 42 case studies of field projects summarized in the appendices of this report.

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IMPACT OF HYDROLOGIC MODIFICATIONS ON WATER QUALITY

By

Joginder Bhutani
Richard Holberger
Peter Spewak
Willis E. Jacobsen
J. Bruce Truett

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Project Officer

Donald J. O'Bryan
Mining and Land Modification Branch
Non-Point Sources Division
U.S. Environmental Protection Agency
Washington, D.C. 20460

Prepared for

OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

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This report describes the scope and magnitude of water pollution problems caused by hydrologic modifications (dams, impoundments, channelization, in-water construction, out-of-water construction, and dredging). Types of pollutants released by each class of hydrologic modification are identified and quantitative estimates are made of the amount of the major pollutant--sediment--that enters the Nation's surface waters as a result of highway and urban construction.

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The report is submitted in fulfillment of Grant Number R-802310-01 by the MITRE Corporation under partial sponsorship of the U.S. Environmental Protection Agency. Work was completed in April, 1975.

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SECTION I

CONCLUSIONS

1. Runoff from highway and urban development construction sites has a severe adverse impact on surface water quality. The preponderance of this impact occurs in or near population centers throughout the Nation, thus degrading the quality of intensively used waters. The overall impact constitutes a problem of national scope with high environmental and economic costs.

2. The major pollutant from out-of-stream construction operations is sediment. Construction runoff also contains smaller but significant amounts of fertilizer, pesticides, oils, lubricants, and washings from concrete and bituminous mixing and finishing operations.

3. Quantities of sediment entering the Nation's waters from out-of-stream construction are not known with exactness, but they are estimated in the range of 40 to 60 million tons per year. Amounts of other pollutants are unknown.

4. Major water quality problems resulting from out-of-stream construction operations are amenable to control by available methods of demonstrated effectiveness, such as mulching, sodding, installation of sediment basins, small dams, diversion structures, or sediment basins.

5. Dredging operations have the potential for introducing large amounts of toxic materials (from benthic sludges) in close proximity to population centers. The quantities and concentrations of such materials introduced into nearby waters by dredging are not known; therefore, dredging should be regarded as a serious source of water

pollution pending further research on the nature and quantities of its pollutants. Few methods are available for control of pollution from dredging. The effectiveness of available methods is not well known.

6. Operation of dams and impoundments can adversely affect water quality by several mechanisms, including sediment retention, thermal stratification, decomposition of trapped organic material, and nitrogen supersaturation.

7. Demonstrated, effective methods do not exist for estimating the quantities of water pollutants resulting from either out-of-stream construction activities or in-water activities such as dredging. Of the methods available, most are applicable only to out-of-water construction and these are of highly dubious accuracy and validity. A method (developed in this study) for estimating the quantity of sediment lost from construction sites by water erosion yielded results that fell between ± 50 percent of observed losses in 53 percent of the cases tested. In comparison, only 24 percent of the estimates obtained from a widely-used model (the Universal Soil Loss Equation) fell with ± 50 percent of observed values.

8. The lack of available methods for estimating effects of construction on water quality is primarily a result of the absence of measured data rather than lack of theoretical understanding.

SECTION II

RECOMMENDATIONS

In view of the severe adverse effects of certain types of hydrologic modifications on water quality, the unknown but potentially severe effects of other types, and the general scarcity of quantitative data for evaluation, MITRE Corporation recommends that EPA take the following actions:

1. Initiate a program to monitor the release of sediment and other pollutants from actual construction sites in all physiographic regions and climatic zones of the U. S. where large-scale construction is occurring or is expected to occur in the foreseeable future. The intent of this action is to develop a substantial data base for making reliable estimates of pollutant loads from any major out-of-water construction operation in any location. Parameters that should be monitored include site characteristics (soil exposure, slope length, slope steepness), position of construction relative to receiving stream, characteristics of intervening terrain, rainfall, and sediment movement (measured continuously). These are discussed more fully in Section VI of this report under the heading "Recommendations for Improved Loading Functions." The data acquisition program should be based on a thorough statistical design to assure that the range of conditions covered is representative of all climatic and physiographic regions.

2. Acquire data necessary to determine the effects of dredging and in-water construction on the quality of surrounding waters. In particular, the nature, quantities, and dispersion of pollutants introduced by dredging operations of different types and magnitudes operating in different benthic conditions should be determined.

Since the U.S. Army Corps of Engineers has underway a research program on dredged materials (See "Concurrent and Beginning Studies" in Section V), EPA should attempt to obtain dredging data through coordination with the Corp's program. If such a joint effort proves infeasible, EPA should initiate a separate program to obtain quantitative data on the effects of both dredging and in-water construction.

3. Since most construction occurs in or near population centers, its impact on water quality affects drinking water supplies and water-based recreation. In order to develop a clear and easily understood measure of the economic and social costs of construction-induced pollution, EPA should survey affected urban areas to obtain accurate data on the technical and economic impact of this type of pollution on these two strongly affected beneficial uses: water supply and recreation.

4. EPA should move quickly to take advantage of sediment release data from three ongoing or recently completed projects. One is the construction of Vail Pass on Interstate 70 in Colorado, where an inter-agency task force is now designing and/or implementing a data acquisition program. The other two are urban/suburban construction areas near South Lake Tahoe, California, and Germantown, Maryland, where runoff and sediment release has been carefully monitored by state and local authorities and where unusually complete records of construction operations and site parameters are available in unreduced form. (See Case Studies 15 and 18 in Appendix B). These three projects offer an opportunity to acquire sound data at relatively little effort which would augment substantially the currently available data base on effects of out-of-water construction.

SECTION III

INTRODUCTION

PURPOSES OF THE STUDY

This study deals with a class of nonpoint sources of water pollution termed "hydrologic modifications"--activities that disturb natural flow patterns of surface water and groundwater. The study has two principal purposes, each of which is intended to serve a different group of potential users:

- To describe and to determine the magnitude of water quality problems caused by the following categories of hydrologic modifications:
  - construction
  - dams and impoundments
  - channelization
  - dredging
  - land reclamation activities

  Information on the nature and magnitude of water quality problems from those activities, determined on a nationwide basis, is intended for use in EPA's program planning process to aid in R&D program formulation and fund allocation.

- To develop "source loading functions" for predicting quantities of water pollutants released by out-of-stream construction activities. These functions are intended for use by technical investigators to estimate the amount of sediment entering a watercourse from construction sites of known size and location.

A thorough survey was made of available information on the effects of construction, dredging, and other types of hydrologic modifications for the purpose of assembling a data base to meet the above two objectives. In the process of compiling and analyzing data, about 40 case studies, most of which reported field measurements, were summarized to present relevant data from each study. These data summaries constitute an unusual and concise compilation of detailed, quantitative data, some heretofore unpublished, on the water quality effects of hydrologic modifications. The summaries are presented in the appendices to this report.

The subjects of groundwater pollution, post-construction effects of out-of-stream construction (such as runoff from impermeable areas), offshore construction, and ocean disposal of dredged materials were specifically excluded from this study.

SUMMARY OF RESULTS

Magnitude of Problem

The relative severity of water pollution problems caused by each major category of hydrologic modification was determined to provide a basis for assignment of research priorities and allocation of funds. In terms of quantity and very probably in terms of overall impacts, the largest pollution load from most categories consists of sediment, and the second largest for all categories except dredging consists of agricultural chemicals.

Basic findings pertaining to the nature and magnitude of resulting water quality problems are outlined, without attribution or qualification, in the following subsections, and are further summarized in Exhibit 1. This summary information is expanded and details are given on data sources, methods, and limitation of results in Section IV and V of the report.

Exhibit 1. **SUMMARY ASSESSMENT OF PROBLEMS ASSOCIATED WITH HYDROLOGIC MODIFICATIONS**

Type of Hydrologic Modification	Major Pollutants	Quantity of Pollution/Year (Nationwide) (tons)	Proximity to Population Centers	Geographic Dispersion	Assessment of Water Quality Problem (Range)*
Construction of Transportation Facilities	Sediment	25 million	90% close 10% remote	Dispersed (concentrated near cities)	Serious (No. 1)
Urban Construction	Sediment	15 million	Close	Dispersed (concentrated in or near cities)	Serious (No. 2)
Dredging	-Sediment -Heavy metals -Other toxic materials	Unknown Unknown Unknown	70% close	Concentrated in coastal areas	Serious (No. 3)
Dams and Impoundments			Generally remote	Generally dispersed (dams concentrated on certain rivers	Locally Serious (No. 4)
Construction	Sediment	Unknown			
Post-Construction Operation	-Organic decomposition products -Nitrogen super-saturation	Unknown			
Channelization	-Sediment -Organic decomposition products	Unknown	Generally remote	Dispersed	Not Serious (No. 5)
In-Water Construction			Generally close	Dispersed	Not Serious (No. 6)
Construction	Sediment	Unknown			
Post-Construction Operation	Oil, fuel, BOD	Unknown			

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*Assessment and rank are based on judgement of present authors, and are relative to other hydrologic modification in this table.

Construction of Transportation Facilities -

Construction and maintenance of highways and other transportation facilities cause three major types of pollution of surface waters. First, large quantities of sediment enter the water as a result of erosion from exposed areas of top soils and subsoils. Erosion from road construction sites is particularly severe because of the steep slopes involved in this type of construction. Second, runoff often contains fertilizers, pesticides and other agricultural chemicals used in planting operations to stabilize exposed soils. Third, runoff contains oil from machinery and washings from concrete or bituminous mixing and finishing operations.

Runoff from transportation facilities construction sites releases an estimated 25 million tons of sediment annually to the Nation's surface waters. This amount represents the highest rate of pollutant release for any of the types of hydrologic modifications for which quantitative estimates could be developed. Available data were not adequate to permit quantitative estimates of agricultural chemicals, oils, and other chemicals. The rate of sediment release, in terms of tons/unit area affected by construction, is the highest for any of the activity categories considered. This rate of pollutant release could be greatly reduced (up to 90 percent) by application of proven control measures.

About 10 percent of future roadway construction is expected to occur in nonurbanized areas; thus about 22 million tons impact annually on the surface waters of heavily populated centers. Even this reduced amount leaves transportation construction as the largest contributor (among those activity categories evaluated) of total pollution load to the surface waters of densely populated areas.

Urban Construction -

The general characteristics of pollution from this category of construction activities are generally similar to pollution from highway construction, except that the rate of sediment release per unit of disturbed area is lower.

Urban construction releases about 15 million tons of sediment each year to surface waters in or near heavily populated areas. This release can be greatly reduced (up to 90 percent) by the use of control measures.

Dredging -

Dredging operations impact upon water quality primarily by causing resuspension or redissolving of polluting materials on the bottom of the waterbody. This resuspension or redissolution occurs when the material is being removed, when it is being lifted from the water or otherwise transported, and when it is being disposed of, either by dumping back into the water or on land. In the latter case, the pollutants are in runoff or seepage to groundwater.

The nature of the pollution caused by dredging is in large measure dependent on the material being dredged. The major pollutant, in terms of mass or volume, is sediment; however, other substances such as toxic materials that had settled as a sludge covering the area being dredged, may be far more damaging to marine life or other beneficial uses of the surrounding waters.

Few studies have been made that quantify the effects of dredging on certain water quality parameters in a limited situation (dredging of small lakes; dumping of dredged materials in bays; runoff from land disposal sites). The available data are grossly inadequate to permit quantification of the effects of dredging in general.

A large volume of dredging occurs in the U. S. - about 400 million cubic yards/year and increasing. Dredging is known to produce adverse effects on the quality of surrounding waters. A large proportion of dredging occurs near densely populated areas. Dredging is therefore considered by the authors as a very important, although unquantified, source of water pollution that should be the subject of immediate and intensive research.

In-Water Construction -

No data were found on the effects of in-water construction (pile driving, bulkhead construction, etc.) on quality of surrounding waters. Because of the nature of this type of activity, its effects were assumed to be similar to dredging. The number of in-water construction projects is rapidly growing and is expected to reach 25,000 in 1975, most of which are relatively small (for example, construction of private docks).

Because of the nature, magnitude, and geographic dispersion of such projects, in-water construction does not seem to be a serious source of water pollution. The post-construction operation of in-water facilities such as docks, marinas, over-water restaurants, etc., will be a source of oil releases and possible release of sanitary wastes. The latter can generally be controlled through application of existing water pollution control regulations.

Dams and Impoundments -

Much of the construction of these facilities occurs under dry condition after diversion of the stream to a temporary bed. Such construction produces water quality impacts similar to those of highway construction: high sediment loss from exposed subsoil, washings from concrete mining and finishing operations, etc. That portion of construction which occurs in-water can produce high sediment loss during excavation dredging. Some studies to determine effects of dam and tunnel construction have monitored turbidity of the stream upstream and downstream of the construction site, and in a very few instances have monitored suspended solids concentration. Because of the poor correlation between turbidity and suspended solids measurements, the available data have not proved adequate for estimating quantities of sediment loss.

Post-construction operation of dams and impoundments affects the quality of downstream waters by several mechanisms:

- Trapping and retaining sediment. This alters the natural equilibrium of sediment downstream of the reservoir, causing scour and erosion. Also, trapped sediment tends with time to fill the reservoir when accumulated sediment is dredged out, resuspension of sediment and other materials may produce abnormally high concentrations that adversely affect aquatic life downstream.

- Thermal stratification. Stable layers of water having different density, temperature, chemical and biological makeup are formed in the reservoir.

- Decomposition of trapped organic material. The reservoir accumulates decomposition products, which can reduce the level of oxygen dissolved in the water.

- Nitrogen supersaturation. Violent mixing of air and water released through turboelectric generators or in high velocity tailwash causes the water to become supersaturated with nitrogen from the air. This condition kills fish downstream.

- Surface evaporation. The large, relatively warm surface area of an impoundment permits rapid evaporation of water, thus increasing the concentration of salts and other dissolved and suspended constituents in the water remaining in the impoundment.

Dam and reservoir construction operations may have a severe local impact on downstream waters, primarily from silt and concrete washings. The activities that cause these effects may extend over a protracted period, perhaps over a number of years for large installations. The activities are reasonably confined and the water quality effects are amenable to demonstrated control measures. Since large dams are not built with great frequency and their construction sites are usually remote from major populations centers, pollution from dam construction is not judged to be a major problem of continuing nature.

Post-construction operation of dams and reservoirs, on the other hand, presents a continuing problem in some regions. Nitrogen supersaturation has caused fish kills in the Pacific Northwest and in Canada. In other regions, reservoirs containing organic matter have caused municipalities to treat their water supply for taste.

Available data were not adequate for making quantitative estimates of water pollutant loads resulting from either construction of dams or post-construction operations.

Channelization -

Construction and stabilization of channels for purposes of drainage, irrigation, and stream realignment cause severe problems of erosion and sedimentation. Some of these effects cover broad areas such as the deltaic region of Louisiana. About 20,000 miles of channel modifications exist in the United States, 77 percent of which is in 10 states that are coastal or border the Great Lakes.

This study revealed essentially no information on the water quality effects of channelization other than the fact that it introduced sediment into surface water. Since much of the channelization occurs in coastal states, the introduction of sediment into estuarine areas would adversely affect the survival of young fish and other aquatic species in these rich breeding areas. The water quality impact therefore takes on a more serious aspect than would be the case if the channelization projects were more uniformly distributed geographically.

Measures for Controlling Pollution from Hydrologic Modifications

Conventional methods for controlling sediment loss from out-of-stream construction sites typically range in effectiveness from 50 to 90 percent. Combination of these methods with flocculation can increase effectiveness to over 96 percent. Sediment control measures are not practiced uniformly in all parts of the Nation. Of the areas surveyed, control measures are most stringently applied in Maryland, the Virginia suburbs of metropolitan Washington, D.C., and in parts of California.

Methods for short-term control of sediment include covering denuded surfaces with gravel, straw, chemical binders, etc; construction of sediment-retention ponds; flocculation; and filtering runoff through strawbales. These short-term measures are followed by quick revegetation of exposed areas by a variety of cover plants. Control costs typically range from about $400 to $1500 per acre (1971 dollars). However, when benefits are considered such as cost of soil lost, damage to stream, and increased water treatment costs when receptor stream is a drinking water supply, the costs of sediment control are approximately offset by the value of the benefits.

Source Loading Functions for Predicting Sediment Loss from Construction Sites

Two loading functions were fitted to sediment runoff data from 10 construction areas. Both functions were of the form of an established sediment-loss equation (the Universal Soil Loss Equation) modified by a "sediment delivery ratio". Factors included in the functions are:

- rainfall
- soil erodibility
- slope-steepness
- cropping management
- erosion control practice

One of the functions also includes distance from construction site to stream; the other function includes the percent of watershed area disturbed by construction.

Comparison of sediment losses predicted by these equations with observed losses indicates that, for the equation involving the distance-to-stream factor, about 53 percent of the predictions fall within a range of ± 50 percent of observed values, and 90 percent of predicted values lie within the range between one-fifth to five times the observed values. For the function involving percent of watershed disturbed by construction, the agreement between predicted and observed values was not quite this close.

These functions were based on data covering a substantial range of soil types, topography, and climate. The data do not, however, reflect conditions in all parts of the Nation. Available information was not adequate to estimate how closely the sediment loss predictions from the equations could be expected to agree with observed losses under conditions not included in the data used to fit the loading functions.

SECTION IV

NATURE OF WATER QUALITY EFFECTS OF HYDROLOGIC MODIFICATIONS

The diversity of water pollution effects of hydrologic modifications requires segregation of the various types of activities that modify the hydrology into more easily defined categories. The following activity categories are used in the present study:

- Transportation (linear configurations)
    - Highways, pipelines, transmission lines
- Urban Development (areal configurations)
    - Residential and commercial developments
- Dams, reservoirs and impoundments
- Dredging
- Channelization
    - Navigation, stream alignment, flood control
- In-water construction
    - Docks, marinas, bulkheads

TYPES OF POLLUTANTS

Each of the above categories has the potential for releasing a variety of polluting substances into surface waters, both during the construction phase and post-construction or operational/maintenance phase. When attention is focused on the construction phase, one water-polluting material--sediment--appears to overshadow all others, certainly in terms of overall quantity added to the receiving waters and very possibly in terms of total economic and ecologic impact.

Damage from sediment appears in various forms. Erosion damage to construction sites is evidenced by gullied slopes, waterways, and channels; washed-out roads; undercut pavements and pipelines; clogged drains and sewers; flooded basements; and dirtied work areas. Revegetation may be hindered by the loss of topsoil. All of these effects cost the contractor time, money and resources.

An exception to the generalization that sediment is the major cause of water pollution may possibly be found in the category of dredging, where other types of materials such as heavy metals and other toxic substances may cause more serious pollution effects.

The nature of the water quality impact of the above listed categories of hydrologic modification activities is shown by two exhibits. Exhibit 2 shows the relative amounts of various types of pollutants released by each type of activity, and indicates the beneficial and adverse effects on the receptor water body. The relative quantity (or release rate) of each pollutant type is shown as three levels: high (H), moderate (m), and low (L). For sediment, the release rate was estimated relative to the release rate from a predisturbed land surface (which may have been forested, grass covered or poorly vegetated) or a predisturbed benthic area. For other types of pollutants, the quantities released were estimated relative to the concentrations of the same type of pollutant in urban surface runoff. These estimates of pollutant quantity or release rate were made by the present authors and are not based on field measurements or data reported in the literature.

Exhibit 3 identifies in greater detail the nature of specific pollutants introduced by various types of hydrologic modification activities, and indicated the nature of the effects from each class of pollutant.

GENERAL FACTORS AFFECTING WATER QUALITY INPACT

Short-Term Nature of Construction Activities

An alleviating factor in construction work, as contrasted with other nonpoint source (NPS) activities which generate water pollution, is that construction is a relatively short-term activity--disturbances or

Exhibit 2. EFFECTS OF CONSTRUCTION PROJECTS ON WATER QUALITY

CONSTRUCTION ACTIVITY	RELATIVE QUANTITY RELEASED BY CONSTRUCTION[a]							EFFECTS OF POLLUTANTS	
	SEDIMENT	NUTRIENTS	DISSOLVED SOLIDS HEAVY METALS	SALINITY	BIODEGRADABLE ORGANICS	REFR. ORGANICS PESTICIDES	OILS AND SYNTHETIC CHEMS.	BENEFICIAL	ADVERSE
OUT-OF-STREAM ACTIVITIES (EARTH MOVING)									
• AREAL (Suburban Devm't -- residences, streets, shopping centers, parking lots, public buildings; Business/Commercial Devm't; Reclamation Landfills -- tunneling spoil disposal[b], dredging spoil on-land, earth dams. Construction -- dams, reservoir areas, bridges.)	H	M	L	L	L	L	L	Sediment produced which may sustain a receptor stream at equilibrium suspended sediment load; can help remove ions in receptor water body by adsorption.	May alter the physical and and biological character of the receptor water body, if subjected to excessive sediment. Results in costly loss of flora and fauna, stream cross-sectional changes, altered flow regimes, and added water treatment requirements. Biostimulation of water bodies from nutrient runoff. May cause siltation of downstream reservoirs.
• LINEAR (Highways; Railroads; Pipelines; Power Lines; Channels/Canals/Flumes/Floodways/Drainage Ditches; Levees)									
IN-STREAM									
• Dredging Operation/In-Water Channel Excavation, Stream Realignment	H	M	M	L	L	L	L	Suction dredging of benthal deposits may remove undesirable heavy metals and other chemical pollutants to accelerate recovery of polluted	Local temporary increase in suspended sediment and turbidity with potentially damaging effects on marine life and degraded water quality for consumptive uses. Can physically remove shellfish from their habitat. Can change channel shape, with ensuing scour or aggradation imposes requirements for grade control structures, concrete linings, or rip rap to stabilize the channel.

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[a] H(high), M (moderate) or L (low) release rates are estimated relative to expected yield from predisturbed surface on benthetic areas for sediment, and relative to urban runoff for chemical pollutants.

[b] Outflow from exit considered to be a point source.

Exhibit 2. EFFECTS OF CONSTRUCTION PROJECTS ON WATER QUALITY

CONSTRUCTION ACTIVITY	RELATIVE QUANTITY RELEASED BY CONSTRUCTION							EFFECT OF POLLUTANTS	
	SEDIMENT	NUTRIENTS	DISSOLVED SOLIDS HEAVY METALS	SALINITY	BIODEGRADABLE ORGANICS	REFR. ORGANICS PESTICIDES	OILS AND SYNTHETIC CHEMS.	BENEFICIAL	ADVERSE
IN-STREAM (Cont'd)									
• Dredge Spoil Dumping in Water, In-Water Fills, Causeways, Retarding Basins, Levees, Floodwalls	H	M	M	L	L	L	L	May create new land for waterfowl habitats and decrease levels of insect breeding in filled-in marshes. Stream blockages provide storm water storage and trap silt, provide fish and wildlife habitat, aesthetic improvement.	Constructed channels scour heavily during flooding. Can smother marine life on bottom, destroy fin fishes, lower dissolved oxygen levels, increase turbidity thereby reducing light transmission. Change original fish and wildlife habitat. Aquatic life stressed by temperature, chemical and biochemical equilibria changes.
• Installation of Piles, Bulkheads, Dikes Marinas	M	L	L	L	L	L	L		Benthic penetration and some disturbance of bottom material ensues, causing local resuspension of sediments.
• Channelization (Stream Realignment, Clearing and Snagging)	M	L	L	L	L	L	L	Improves flow efficiency and navigation. BOD lower with lower detritus.	Temporarily increases suspended sediment and turbidity. May decrease concentration time of peak runoff and increase flooding downstream Removes obstructions used by fish for protection, food support, and breeding areas.

Exhibit 3. WATER POLLUTION FROM CONSTRUCTION ACTIVITIES

CAUSE/EFFECT MATRIX

POLLUTANT		SOURCE ACTIVITIES/OCCURRENCE	QUANTITY[a]	EFFECTS	
CLASS	MATERIALS			BENEFICIAL	ADVERSE
Physical					
• SEDIMENT	Inert and organic particles; colloids; microorganisms (Note: during transport, the sediment load comprises the suspended load plus the bed load.)	Land-Disturbing Operations: Surface-clearing, grading, excavating, trenching, stockpiling; (Note: Subsoils often have different erodibility characteristics than surface soils)	H	May provide material to maintain a receptor stream channel in equilibrium, i.e., provide adequate suspended sediment to prohibit erosive degradation of a fluvial channel. In-stream sediment required in formation of silt-laden farmlands along flood plains and near river mouths. Fine-grain sediment helps in the removal of ions which adhere to and are transported by particulates, which settle to the bottom. Dredge spoil disposal may also create new land areas (for building sites, beach restoration, waterfowl habitats) and decrease vectors in marsh-filling.	May exceed equilibrium suspended load of receptor stream altering many physical and biological characteristics of the channel; these include channel aggradation, silting of reservoirs, undesirable effects on marine life such as blanketing and smothering of benthic flora and fauna; altering the flora and fauna as a result of changes in light transmission and abrasion, destroying or altering the species of fish due to changes in the flora and fauna upon which the fish depend, or obstruction of their gill function. Also a need may arise for excessive treatment (sedimentation, clarification) prior to consumptive use for municipal, industrial, or irrigation purposes. Channel siltation can adversely affect its capacity to carry flood flows or support navigation and recreation. Dredge spoil disposal may destroy land areas (salt marshes, wildlife refuge, vegetated coverage), block flow circulation or increase vectors in the spoil pile.
		Channel Modification: Dredging, waste disposal, excavation, fill, penetration of bed	M		
		Cleaning Operations: Aggregate washing, cleaning of masonry surfaces, forms and containers	L		

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[a] H (high), M (moderate) or L (low) release rates are estimated relative to expected yield from predisturbed surface on benthetic areas for sediment, and relative to urban runoff for chemical pollutants.

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Exhibit 3. WATER POLLUTION FROM CONSTRUCTION ACTIVITIES

CAUSE/EFFECT MATRIX

POLLUTANT		SOURCE ACTIVITIES/OCCURRENCE	QUANTITY	EFFECTS	
CLASS	MATERIALS			BENEFICIAL	ADVERSE
Chemical					
• NUTRIENTS	Ammonia, orthophosphates, polyphosphates, organic N, organic P	Fertilization of reestablished vegetal cover	L	Stimulates growth of plants and grasses on areas denuded by construction (especially on slopes), thereby reducing soil loss in rain storms	Nutrients, especially from excessive application of soluble fertilizers, will be transported from new-growth surfaces at construction sites in the runoff of precipitation; by then stimulating growth of algae and marine plants, nutrients can have adverse effects on chemical exchange processes, leading to eutrophication and lowered oxygen levels. In addition to the biostimulation impacts, large concentration of unoxidized nitrogen (organic nitrogen and ammonia) could represent a significant oxygen demand in the receiving waters.

Exhibit 3. WATER POLLUTION FROM CONSTRUCTION ACTIVITIES

CAUSE/EFFECT MATRIX

POLLUTANT		SOURCE ACTIVITIES/OCCURRENCE	QUANTITY	EFFECTS	
CLASS	MATERIALS			BENEFICIAL	ADVERSE
• DISSOLVED SOLIDS/ HEAVY METALS	Ionic Hg, Pb, Zn, Mn, Co, Cr, Ag, Cd, As, Cu, Al, Fe	Derived from construction wastes such as discarded metallic frames, ducts, pipes, wiring, beams, gypsum board; also from fuels, paints, pesticides, and other construction chemicals. Also, concrete operations produce NPS, e.g., spilled cement, washing water, curing compounds.	L	A light, distributed concrete spillage or wash disposal may act as a cementitious stabilizer to reduce soil erosion; also it will add alkalinity which could correct acid soils	When these materials weather, decompose and disintegrate (recognizing that many of the substances such as plasterboard are only slightly soluble in water), the resultant oxides and salts dissolved in water bodies may damage or destroy aquatic organisms; also higher concentrations of certain of the dissolved solids are toxic to humans.
		Dredging activities may reintroduce and disperse within the water column dormant layers (confined by silt deposits) of heavy metals trapped in bottom sludge deposits generally originating over long time periods from point industrial sources and urban runoff.	H Note: may be significant in certain sluggish rivers, lakes, or bays, especially in first-dredging; generally insignificant buildup would occur by the time that maintenance (repeat) dredging is undertaken	Suction dredging and disposal of undesirable chemicals in benthal deposits may accelerate recovery of polluted water bodies, in parallel with introduction of clean inflows.	Dredging may mechanically reintroduce these chemicals into waters, with subsequent diffusion and increase in undesirable impact described above.
• SALINITY	NaCl $CaCl_2$	Produced from saline ice-removal compounds in cold climates (construction roads), dust control on graded areas, and concrete additives (freezing-depressant additives or early strength-enhancing agents, curing compounds). Affected by hydraulic changes resulting from channelization.	L Note: minor level, depending on nature and seasonality of construction activity	Use of salt compounds allows continuation of projects throughout a greater range of climatic conditions, reduces air pollution from dust	Increased salinity of water impacts upon nature of marine life-plants and animals--indigenous to the region; quality may be degraded for municipal, industrial, or irrigation uses.

Exhibit 3. WATER POLLUTION FROM CONSTRUCTION ACTIVITIES

CAUSE/EFFECT MATRIX

POLLUTANT		SOURCE ACTIVITIES/OCCURRENCE	QUANTITY	EFFECTS	
CHEMICALS	MATERIALS			BENEFICIAL	ADVERSE
• BIODEGRADABLE ORGANICS	Submerged or floating brush, lumber, tree trunks or limbs, paper, fiberboard	Improper disposal of building products or poor clearing and clean-up practices	L	Larger submerged objects may serve as a temporary habitat of fishes. Permitting growth, wood chips, and similar matter to remain in place in a future inundation area will temporarily reduce out-of-stream erosive losses by serving as a precipitation energy absorber and a sheet runoff retardent.	In degrading of the organics an oxygen demand is exerted on the receiving waters. The dissolved oxygen depression, or large resultant fluctuations in DO, can lead to death of aquatic organisms, severe changes in types and numbers of aquatic organisms, obnoxious odors, and nuisances such as aesthetic impacts, clogging of pumps, screens, etc.
• REFRACTORY ORGANICS/ PESTICIDES	Highly persistent chemicals, heat resistant, or effectively non-degradable, e.g., certain pesticides and other synthetic organics (solid construction materials and tools of polyvinyl chloride, thermoplastic polyesters, rubber, and epoxy fibers and liquid chemicals for treatment of walls, adhesive applications crack-sealing, waterproofing, painting, and curing operations.) Major categories of insecticides include the chlorinated hydrocarbons—complex organic molecules of C,H,Cl—such as chlordane, malathion, DDT, and the phosphorothioates—C,H,P. Herbicides include 2,4,D and 4,5,T.	Improper care in construction applications, overusage, spillage. (Note: some of these types of pollutants, particularly the solids, are expected to remain at the source or point of application, with negligible overland transport). Trend in construction in use of biocides is away from inorganics and toward synthetic organics for use as insecticides, herbicides, fungicides, and fumigants.	L Note: expected level of production is very low because most pesticides are too expensive to be wastefully applied, resulting in efficient or optimal usage.	Underslab and foundation treatment with long-lasting insecticides, especially for termite control, is an important usage; herbicidal treatment of soil areas to remove herbaceous and woody plants that obstruct development and for weed control prior to revegetation is necessary in many construction projects.	Toxic to a wide spectrum of marine biota; can concentrate (by biomagnification) in aquatic organisms, and the effects can be transmitted through higher levels of the biological food chain up to humans. Most biocides show a tendency to accumulate in bottom muds. Earth-moving may reexpose pesticides previously applied to a site, e.g., if used previously for agriculture.

Exhibit 3. WATER POLLUTION FROM CONSTRUCTION ACTIVITIES

CAUSE/EFFECT MATRIX

POLLUTANT		SOURCE ACTIVITIES/OCCURRENCE	QUANTITY*	EFFECTS	
CHEMICALS	MATERIALS			BENEFICIAL	ADVERSE
• OILS AND SYNTHETIC CHEMICALS	Petroleum products such as oils, grease, tars, asphaltic materials, fuels, solvents; paints, detergents, soaps, sealants, adhesives, chemical soil stabilizers	Introduced into soils through improper construction and maintenance practices, (such as not using adequate caution and methods in disposing of oil wastes, transporting and transferring fuels and lubricants, oil-laden rags, and degreasing compounds), and from spills, for example, from storage tanks. Spillages during routine construction and leaks from trucks and other machinery are also serious considerations. Production of water-bitumen mixtures from road paving, roofing, and waterproofing jobs can also cause NPS concern.	L		Some of these chemicals float over water, some become entrained in water --absorbed on sediment--and some dissolve in water; but all are extremely difficult to control after entering water bodies. These categories of substances impair the use of water for drinking and for contact sports because they impart persistent odors and tastes to water. Some may block the transfer of air through a water-floating substance interface, suffocating aquatic plants, organisms and fish. Some petroleum products contain organo-metallic compounds and other impurities toxic to fish and other organisms.
Biological					
• COLIFORM	Disease-causing pathogens: soil organisms and those of human and animal origin (bacteria, fungi, viruses).	Improperly planned and managed construction sites where inadequate sanitary conditions prevail.	L M Note: Majority of biological pollutants exist in topsoil layers where they feed on dead organisms; however, construction often disturbs the lower subsoils.	Sludge from wastewater treatment plants may promote and accelerate the restoration of graded areas.	Can cause diseases in humans and animals when released or made available in water bodies.

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displacements of soil and vegetal cover generally cause only temporary and localized increases in the potential for erosion or production of other pollutants. During the interval that the land is disturbed, the soil loss or the runoff of chemicals will hinge on probabilistic intensities, durations, and runoffs of precipitation. Mining and agricultural pursuits, by comparison, might be expected to last for decades or even indefinitely. A possible exception to short-term nature of hydrologic modification acitivities is maintenance dredging, that is, redredging to preserve navigation channels at specified depths and widths. This activity may be repeated intermittently over the useful life of a channel.

Climate and Terrain

Construction in climates not conducive to growth of vegetation is frequently followed by prolonged environmental recovery times. Slow recovery or restoration of certain lands (for example, the tundra of Alaska and arid areas of the Western U.S.) following roadbuilding or pipelining activities is due primarily to a short growing season or lack of water to reestablish vegetation rapidly. On the other hand, the adverse conditions may be offset from an erosion potential standpoint by minimal precipitation or essentially no runoff during periods when the ground and streams are frozen solid.

Flat terrain or lands having low annual rainfall (or rainfall distributed seasonally in a way that results in minimal precipitation or runoff during and immediately following the construction activity) may be practically excluded as major nonpoint source problem areas. Moreover, in regions having the highest annual precipitation, little erosion normally occurs naturally because of the dense ground cover; however, once this ground cover is disturbed by construction, such regions could present formidable erosion problems during and following the construction activities.

SECTION V

PRESENT AND FUTURE POLLUTANT LOADS FROM HYDROLOGIC MODIFICATIONS

Construction activities and other types of hydrologic modifications occupy an unusual position on the spectrum of non-point sources of pollution. They are by no means the major producers of their most voluminous pollutant--sediment. The annual sediment yield for such major classes of construction activities as transportation facilities and urban development is estimated at some 56 million tons,(5-1) which is small compared with the estimated 2-billion ton yield from agricultural activities. Relative quantities of other types of pollutants such as fertilizer and pesticides from construction are even smaller in comparison to agricultural and urban runoff.

Experts in the field of sedimentation have rated the quantities of sediment reaching streams from seven classes of non-point sources as follows:(5-2)

(1) agricultural tillage
(2) grazing
(3) highway construction and maintenance
(4) timbering
(5) mining
(6) urban land development
(7) recreational land development

However, when pollution from construction activities occurs, its impact can be severe in terms of local environmental impact. Construction activities frequently occur in small watersheds in or near densely populated areas. When a recreational lake fills with silt, a once-clear stream becomes turbid, a drinking water supply requires additional treatment, or a local aquatic species is destroyed, the effects are very conspicuous and can reasonably be assigned high economic costs.

BETTER PROCEDURES NEEDED FOR ESTIMATING POLLUTANT LOADS

Although estimates of pollutant loads from various types of nonpoint sources--usually on a nationwide basis but sometimes for localized areas--have appeared in the literature,(5-3),(5-4) the availability of quantitatively-based loading functions is expected to produce estimates of improved accuracy. In addition to the loading functions for construction activities presented in Section VI, similar functions for other types of nonpoint sources (agriculture, forestry and mining) are being developed in a companion study being performed by Midwest Research Institute. The application of all of these functions to a specific region, watershed, or across the nation is expected to yield better estimates of nonpoint source pollutant loads than those currently available.

Prior to the application of the source loading functions, it is of interest to examine some of the current and projected estimates of pollutant loads from hydrologic modifications. This is done in the following subsections. A projection period of 1973-1990 was arbitrarily assumed, since data for highway construction, housing construction, and population change were available for this interval.

It should be recognized that the available procedures for estimating pollutant loads vary greatly from one category of activities to another. For example, research by a limited number of investigators, in particular M. G. Wolman and his colleagues at Johns Hopkins, have produced results that permit quantitative estimates of sediment load from construction of urban and highway construction.(5-4),(5-13) On the other hand, research leading to procedures for estimating pollutant loads from dredging and in-water construction is only now being undertaken by the Corps of Engineers. Even less quantitative information is available on the water pollutant loads caused by construction of open channels, floodways, drainage mains and laterals, and irrigation canals for agricultural purposes. There are statistics that indicate trends in the cumulative amount and magnitude of these activity categories for which cause/effect information on water quality is not available. In such cases, this information on gross measures of activity will be presented in the following subsections, since it is indicative of the amounts of water pollution that would result in the absence of control measures.

POLLUTANT LOADS FROM CONSTRUCTION OF TRANSPORTATION FACILITIES

The construction of transportation ways, especially highways, is one of the most conspicious, and, in many local affected areas the largest sources of water pollution. The pollutant is mainly sediment, but runoff from construction sites may contain fertilizers, pesticides, and other agricultural chemicals used in planting operations to stabilize exposed soil as well as washings from concrete or bituminous mixing and finishing operations.

Present Level of Highway Construction

In testimony before a Congressional Committee in April 1974,(5-5) Secretary of Transportation Claude Brinegar stated that the Nation's highway system totals some 3.7 million miles (3.1 million rural, 0.6 million urban), which represents a 12 percent increase since the end of World War II. These total mileage figures correspond generally to the total road and street mileage data for 1971.(5-5) The 12 percent increase over the (approximate) 25-year period from the end of World War II through 1971 implies an average growth rate of just under 0.5 percent per year in the total highway system.

In 1972 the Federal Highway Administration developed statistics on the land area covered by the Nation's highway and streets. The total system covers some 9.4 million acres (paved surfaces and shoulders) and includes within its rights-of-way a total of 21.7 million acres or about 34,000 square miles (5-6). This affected area is broken down as shown in Exhibit 4.

It is assumed that the total areas shown in Exhibit 4 are based on data for the preceding year as reflected in Highway Statistics - 1971 (5-5), and that the total acreage in each road-type category corresponds to the total number of miles in these same categories (as presented in Table M-12 of Reference 5-5 and summarized in Exhibit 5.) Estimates of the area covered per linear mile of each type of roadway are presented in Exhibit 6.

In an analysis for different types of roadways (4-lane divided or dual highway, and 2-lane highway) in parts of Maryland having markedly different geographic character (coastal plain, rolling Piedmont and mountainous areas), Wolman and Schick (5-4) found ratios of exposed area per linear mile ranging from 8.8 acres/mile for 2-lane roads in flat country to 25.5 acres/mile for 4-lane highways in rolling country. (See Section VI for additional detail). These authors estimate that construction of a dual-lane highway (arterials) in the Piedmont area of Maryland would yield an average of 3000 tons of sediment per linear mile, and 1500 tons per mile for 2-lane highways (collectors).

The estimated rate of sediment produced annually from construction and maintenance of the Nation's highways has been reported in several sources as about 56 million tons.(5-1) This figure is the same general magnitude as obtained by assuming a 0.5 percent per year rate of increase in construction (i.e., about 0.5 percent of 3.7 million miles total = 18,000 miles new construction per year) and applying an average sediment production ratio of 2200 tons/mile suggested above for Maryland road construction. The result is an estimate of some 40 million tons per year from new construction but excluding maintenance.

Exhibit 4. **LAND AREAS IN U.S. TRANSPORTATION SYSTEM** (5-6)

(Entries in Millions of Acres)

	RURAL		URBAN	
Type of Roadway	Travel Surface*	Right-of-Way	Travel Surface*	Right-of-Way
Interstate	0.33	1.40	0.09	0.31
Primary	1.12	3.26	0.18	0.26
Secondary	0.71	1.91	0.05	0.08
Other	5.44	12.10	1.46	2.39
Total	7.60	18.67	1.78	3.04

*Paved surface and shoulders

Exhibit 5. TOTAL ROAD AND STREET MILEAGE IN U. S. - DEC. 1971 (5-5)

(Entries in Miles)

Type of Roadway	Rural	Urban
Interstate	34,700	8,200
Other Primary	189,100	25,300
Secondary	609,000	27,400
Other	2,356,300	479,300
Total	3,189,100	540,200

Exhibit 6. **LAND AREAS PER LINEAR MILE OF ROADWAY IN TOTAL U.S.**

(Entries in Acres)

	RURAL		URBAN	
Type of Roadway	Travel Surface*	Right-of-Way	Travel Surface*	Right-of-Way
Interstate	9.5	40	11	38
Primary	5.9	17	7.1	10
Secondary	1.2*	3.1	1.8	2.9
Other	2.3	5.1	3.0	5.0
Overall Average	2.4	5.8	3.3	5.6

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*This average area implies a very narrow roadway--about 10 feet. This apparently aberrant result is possibly caused by including unpaved roadways in the total mileage (used as the denominator) but only paved surfaces in the area (used as the numerator in the ratio of acres/linear mile).

Source: Exhibits 4 and 5.

Future Pollutant Loads from Highway Construction

In a report of their pioneering work on measuring and controlling roadside erosion, Diseker and Richardson* stated in 1962 that the 41,000 miles of interstate-type highways yet to be built, plus planned improvement of 750,000 miles of existing primary and secondary roads, will expose some 17 million additional acres of cuts, fills, and ditches that form potential sources of sediment.(5-7) This suggests an overall average of about 20 acres of exposed earth per mile of construction. This ratio is much higher for the construction of a new multi-lane interstate-type highway than for the improvement of an existing secondary road.

Projections of roadway construction of various types in the U.S. during the time period 1968-1990, as derived from the 1972 Highway Needs Report,(5-8) indicate a total of about 350,000 linear miles of new highway construction in the U.S. during this period.** Exhibit 7 gives a breakdown by type of roadway. Applying the right-of-way width data from Exhibit 6, about 3,500,000 acres will be exposed during this construction.

If it is assumed that sediment from construction of local streets is accounted for in estimated yields from residential development, the above-cited yield rates (observed by Wolman and Schick) may be applied for arterials and collector roadways to obtain an estimated sediment yield of 325 million tons from highway construction during the period

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* This investigation is summarized in Case Study 2 of Appendix A.

** This figure is interpreted here as not including improvements to existing roadway.

Exhibit 7. PROJECTED INCREASES IN HIGHWAY MILEAGE
(AS DERIVED FROM NATIONAL HIGHWAY NEEDS REPORT)(5-8)
1968 - 1990
(Entries are in thousands of linear miles)

	Total	Rural	Small Urb	Urban
Arterials	81	10	10	61
Collectors	49	19	4	26
Locals	223	-2	28	197
Totals	353	27	42	284

1968-1990. (Since this period is 5 years longer than the 1973-1990 period considered above for aereal construction, the adjusted figure for a 17-year period of highway construction would be about 265 million tons). This figure corresponds to an average annual rate of sediment production from highway construction of 15 tons per year nationwide during this period. This rate is about one-third of the annual rate of sediment production estimated in the preceding subsection for the time period 1945-1971. The lower rate of sediment production is a result of the projected lower rate of highway construction during the 1973-1990 period (18,000 miles/year for 1945-1971 versus 6,000 miles/year for 1968-1990, not including local streets).

POLLUTANT LOADS FROM URBAN CONSTRUCTION

Around the turn of the century, the U.S. became an urbanized country, marked by the threshold at which more Americans lived in cities than in agricultural or rural settings. Urbanization continues today, but in a different guise and for different reasons. Urbanization today is a process of spreading out--of suburbanization.

When urbanization first began, major resources were fairly abundant. As time passed, urban land as a resource became more and more scarce. Transportation systems were improved and the logical result was suburbanization. Today, about 0.04% of the land area of the United States (about 1,500 sq. mi.) is urbanized annually.(5-9) This is considered as a minimum rate for years to come. As of 1972, only 2.5% of the land surface of the U.S. was occupied by cities.(5-2) Presumably, available land will continue to be a valuable resource, but we are also concerned here with other resources that are affected by the development of land resources, particularly the quality of surface waters.

Present Rates of Sediment Production from Urban Development

While urban development is not the largest contributor of sediment in our Nation's streams, it does add substantial amounts that often produce a severe impact on water quality in heavily populated watersheds. It is estimated that an average of 40 to 50 tons of sediment can be expected per acre of urban construction.(5-10) Wolman showed that sediment yields from urbanization ranged from 1,000 to more than 100,000 tons/mi^2/year, which for very small areas may exceed 2,000 to 40,000 times the amount eroded from farms and woodlands in an equivalent period of time. (5-11) The Soil Conservation Service estimates that sediment from construction in general produces 10 times the amount of sediment of land in cultivated row crops, 200 times more than pasture land, and 2,000 times more than timber land.(5-12) Taking population into account, Wolman estimates that in Baltimore County, Maryland, construction for one person results in 1.8 tons of sediment and in Prince Georges County, Maryland, this figure is 0.7 tons/person. (5-13)

Projected Sediment Loads from Urban Development

Several basic quantitative observations relating quantities of pollutant (sediment) produced per unit increase in population form the basis of our estimates of projected pollutant loads from construction. These relations are summarized below(5-13):

1. In Prince Georges County, Maryland, an estimated 700 tons of sediment were produced for each population increase of

1000. (Of this amount, 62 percent or 430 tons was attributed to highway construction and 38 percent or 270 tons to areal construction).

2. In Baltimore County, Maryland, 1800 tons of sediment were produced per 1000 increase in population (of which 36 percent or 650 tons was attributed to highway construction and 64 percent or 1150 tons to areal construction).

3. Approximately 10,000 tons of sediment are produced per square mile of area urbanized. A typical housing unit occupied about 0.000516 square miles (or about 14,000 square feet).

Averaging the sedimentation rates for the two Maryland counties yields a total rate of about 1250 tons per 1000 population increase, or a rate of 480 tons per 1000 population for areal-type construction exclusive of highways. (Local city or subdivision streets are included in the areal development rates discussed below.)

If these rates are applied to the projected population increase of about 54.5 million for the Nation over the period 1973-1990* a total sediment production of 682 million tons is obtained from all construction, or about 263 million tons from areal construction alone.

A second approach to estimating sediment yield from areal construction is to utilize the U. S. Department of Agriculture's projections for new housing(5-14), which total some 48.4 million units over the 1973-1990 time period. This figure, taken with Wolman's estimate cited above of 0.000516 square miles/housing unit, implies that about 26,000 square miles would be affected. At the above-cited yield rate of 10,000 tons sediment per square mile, an estimate of 260 million tons sediment yield for the 1973-90 time period is obtained.

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*An average of the Bureau of Census' Series C, D, E, and F projections as reported in Reference 5-15.

A third approach is to utilize the observation by Guy and Jones(5-2) that about 1500 square miles of land area are urbanized annually in the U.S.; thus about 27,000 square miles would be disturbed over the 1973-90 interval. At the sediment yield rate of 10,000 tons/square mile cited above, a total of 270 million tons of sediment would be produced during the period 1973-90.

Thus three estimates for sediment yield from areal-type construction sources are obtained for the period 1973-1990: 263 million tons, 260 million tons, and 270 million tons. These estimates average to about 264 million tons for the 17 year period, or about 15.4 million tons per year.

SUMMARY OF RESULTS FOR OUT-OF-STREAM CONSTRUCTION: COMPARISONS, QUALIFICATIONS AND CAVEATS

Since quantitative estimates of pollutant loads were developed only for out-of-stream construction categories, it is appropriate that the results be summarized and discussed prior to presentation of results of those types of hydrologic modifications for which available data do not permit quantitative estimates of load.

From the two preceding subsections the following totals are obtained:

	Millions of Tons of Sediment Produced	
	1973-1990	Per Year
Areal Construction(Urban)	264	15
Linear Construction (Roadways)	265	15
Total	579	30

The accuracy of these amounts, which have been computed for the entire United States, is dependent on the extent to which Wolman's observed rates for urbanizing areas and highway construction sites in Maryland may be applied to the entire country. Whether or not the Piedmont area is representative of the entire nation is highly debatable. Further, these rates also assume that construction techniques will remain the same through 1990. Regardless of what control measures may be applied, changes in construction technique may have effects on the duration of activities or the amount of area involved and thus could reduce the amount of sediment produced. Further, while the projections used concerning population are widely accepted, these, too, must be considered as subject to revision in the light of recent trends in population change and economic growth. These estimates are coarse and should be treated as such.

For an area such as Piedmont, the rates presented here are conservative. In the construction area studies by Wolman, sediment yield per square mile per year ranged from 140,000 tons to 1000 tons with an average of 34,335 tons/square mile/year.(5-13) Holeman estimates that sediment yield in the Lake Barcroft area, not 20 miles from the area of Wolman's study, is approximately 20,000 tons per year.(5-16) The rates observed by Knott, et al., in the Colma Creek Study in California were similar. In 1969, the total was 39,300 tons/square mile/year and in 1970 the rate was 26,200 tons/square mile/year with a 2-year average of about 33,000 tons/square mile/year (See Appendix B, Case 8). For some areas of the country with a different climate or with different soils, a figure of 10,000 tons/square mile/year may be considerably higher than the actual rate. However, the areas in which most development will probably take place is closer in climate and geology to the Piedmont area than to places of climatic and geologic extremes such as deserts or artic regions where the sediment yield would be most likely to be less than the estimates quoted here. Therefore, though the rates used in the estimates stated here are conservative for the Piedmont area, they are probably even more conservative for the Nation as whole.

It is the hope and expectation of the present authors that national or regional estimates of pollutant loads from construction sources, as obtained from the source loading functions described in Section VI, will represent much more realistic and accurate results than the rough estimates developed in the present section.

POLLUTANT LOADS FROM DAMS, RESERVOIRS, AND IMPOUNDMENTS

General

Water pollution is caused by this class of hydrologic modifications, both during construction and during post-construction operation. This study revealed limited amounts of quantitative information on the effects of dam and tunnel construction on stream turbidity, and on the effects of impoundments on streambed erosion and downstream water quality. Extensive data were available on reservoir siltation. The available information was not adequate, however, to permit quantitative assessment of the effects of dams and impoundments on water quality at the national level or for specific types of construction sites.

While noting the various adverse effects of dams on water quality, we must also be aware that they provide a valuable resource: a lake for recreational use, fish breeding, and sediment removal, as well as flood control, water supply and electric power generation.

Effects of Construction

In general, the effects of reservoir construction are similar to most other construction activities and depend on the type and size of the dam. Pollution from dam construction can be separated into two phases. In-stream sources include the construction and erosion caused by the diverting structures, excavation in the stream channel, and runoff from the gravel washing operations. Out-of-stream operations include temporary access roads, borrow areas, storage piles, clearing and grubbing operations. The effects of out-of-stream sources are similar to those of other construction activities associated with urbanization. The primary pollutant in both cases is sediment, although other pollutants such as fertilizers and pesticides are sometimes present.

Effects of the Structure

Because the dam structure changes the hydraulics of the stream, it may upset natural hydrologic equilibria and cause the stream channel to change its course and its erosion characteristics. In some cases, downstream salinity is increased because of seepage through saline deposits, evaporation and increased exposure to soluble rocks, all caused by the formation of large bodies of standing water and diversion of the waters for irrigation purposes.(5-17)

Many reservoirs are designed to function as sediment traps. This means that a large portion of the influent sediment settles out of the stream water as it flows through the reservoir. Consequently the effluent stream usually carries much less than its sediment capacity. The stream will tend to restore its equilibrium loading by scouring the downstream channel. If the channel is soft, it will be eroded very quickly. An example of this occurred in the 91.8-mile reach of the Colorado River from the outfall of Hoover Dam to Lake Havasu. Between 1935 and 1951, approximately 152 million cubic yards of sediment were scoured from the river bed and deposited in the lake,(5-2) which averages to approximately 100,000 cubic yards per mile per year. Another example of this effect is shown in Exhibit 8, which depicts a small stream bed in Mississippi that has been degrading at the rate of about one foot per year.

Effects of Reservoir Operation

The water in large reservoirs is frequently stratified, that is, composed of several layers, differentiated by density, usually determined by temperature but sometimes additionally determined by suspended solids concentration. These layers have different dissolved oxygen concentrations, salinities, and biological communities. The quality of water released from such a reservoir depends on the height of the outlet. If stratification is not accounted for in operation of the outlet works, downstream water quality might suffer. Temperature affects the solubility of oxygen and therefore is important in determining the waste assimilative capacity as well as the types of organisms that can inhabit a stream. Releases from stratified lakes must be carefully controlled to prevent damage to downstream aquatic communities and to minimize adverse effects on downstream water supplies.

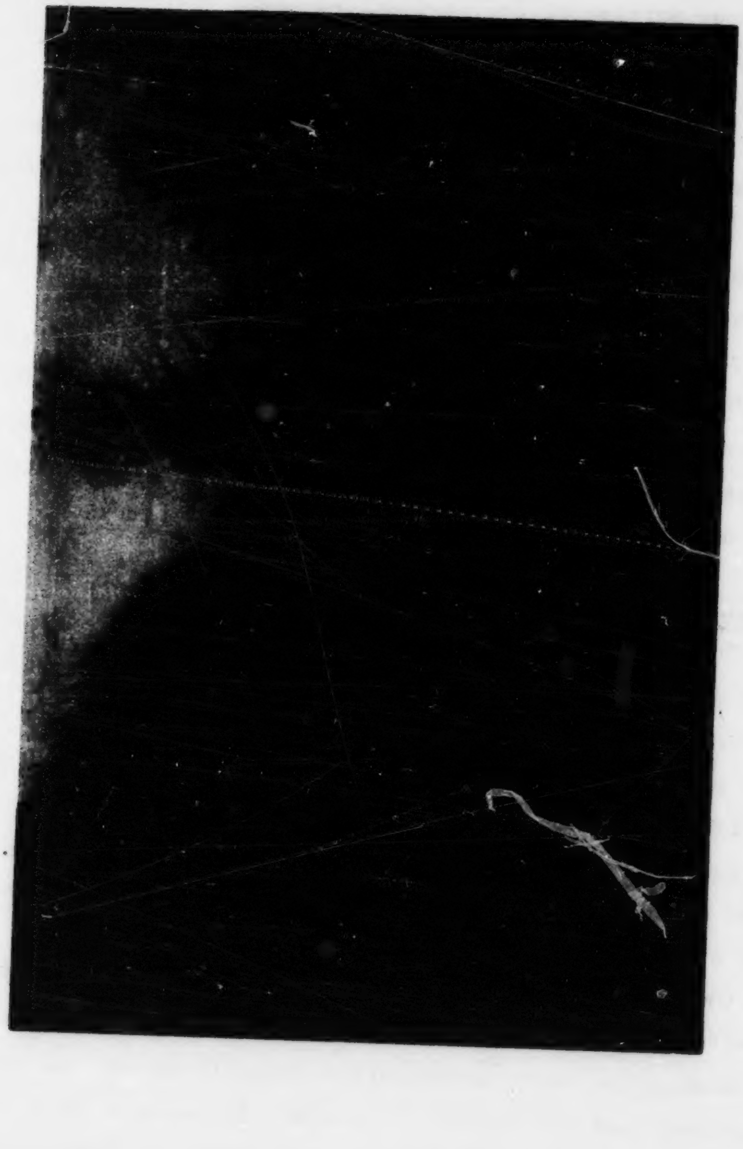

Exhibit 8. Example of Stream Bed Degradation in Small Stream in Mississippi

(Photo Courtesy of USDA Sedimentation Laboratory)

Other characteristics of reservoir discharges that affect downstream quality are the volume and continuity of flow, clarity, salinity, and the presence of toxic chemicals. Intermittent discharges can greatly disrupt the ecology of the receiving stream. (The effects of very clear discharges on increased erosion have already been discussed.) It has been suggested that in some cases, releases could be timed and located to tap density currents containing a relatively large concentration of fine sediments. This would have the effect of reducing downstream erosion as well as extending the life of the reservoir. Benefit would accrue to downstream farmers, since it might be possible to manage the stream load such that rather than eroding his fields (the stream would already contain its maximum load), the stream would deposit some of the nutrient-laden fine sediments.

When water from high-head dams is passed through turbines to drive electric power generators, the violent mixing of air and water can supersaturate the water with nitrogen. (5-18), (5-19) There is some evidence that supersaturation occurs also in the high-velocity spill from high dams. Nitrogen supersaturated water has been responsible for fish kills in the Northwestern States and in Nova Scotia.

Regional and Local Nature of Water Quality Impact

The nature of water quality effects is largely determined by the type and size of dam and the configuration and capacity of reservoir. Any dam will have some effect on water quality, if only in terms of sediment load, but larger dams with high capacity, long-retention reservoirs are more likely to produce the chemical and biological effects associated with thermal stratification.

Low dams that form small reservoirs are used in many sections of the country to provide municipal water supplies. High dams with hydroelectric generators and large capacity reservoirs are located primarily in mountainous areas. Such installations are concentrated in the Appalachian system of the eastern U.S., the Rockies, and the Pacific Northwest. The geographic distribution of hydroelectric generators is shown in Exhibit 9. It is this type of installation that has produced nitrogen supersaturation that caused fish kills.

The large, multipurpose dams located mainly in midwestern and western states have reservoir capacities great enough to cause thermal stratification and concentration of pollutants by evaporation of water from the surface. Our information has not included evidence of nitrogen supersaturation from this type of facility.

Limited Quantitative Data on Water Quality Effects; No Quantitative Projections

Our survey revealed relatively little information on the impact of dams and impoundments on water quality, other than in terms of turbidity which proved of dubious value in estimating pollutant loads. There were some exceptions, however.

Quantitative data are provided on the effects of an impoundment on the decrease in capacity of the Coosa River to assimilate oxygen-demanding wastes by Case Study 19 in Appendix C. This study also reports similar effects observed for European rivers.

Case Study 23 reports the results of laboratory simulation of the effects of impoundment of water in a reservoir upon 22 water quality parameters.

Exhibit 9. LOCATIONS OF HYDROELECTRIC GENERATORS
WITH CAPACITIES OF 25,000 KILOWATTS OR GREATER

	Number of Installations		Number of Installations
Alabama	10	Nebraska	3
Arkansas	1	New Hampshire	5
California	31	New Jersey	1
Colorado	1	New York	6
Georgia	3	North Carolina	7
Idaho	7	Oklahoma	3
Indiana	1	Oregon	9
Iowa	1	Pennsylvania	7
Kentucky	1	South Carolina	4
Louisiana	1	Tennessee	1
Maine	4	Texas	2
Maryland	1	Vermont	6
Massachusetts	5	Virginia	2
Michigan	2	Washington	17
Missouri	3	West Virginia	2
Montana	5	Wisconsin	4

Source: U. S. Geological Survey, Water Resources Development Map, 1969.

Case Study 22 reports interesting comparisons of turbidity measurements upstream and downstream of construction sites at which various sediment control measures were employed. Because of the incomplete status of these projects and poor correlations of these preliminary turbidity data with sediment concentrations, the data were not useful in developing a quantitative relation between sediment loss and construction site parameters.

Because of the sparsity of data, no estimates or projections were made of water quality impact of dams and impoundments, either for specific installations or on a nationwide basis.

POLLUTANT LOADS FROM CHANNELIZATION

Channel stabilization practices that protect either the waterway or the land along the waterway are usually undertaken to prevent loss of valuable property, reduce flood heights, conserve water through diminution of evaporation and transpiration, or to provide and maintain adequately navigable channels. These practices are accomplished by riverbank modifications and by forming cutoffs; by constriction of water to deep and narrow channels to minimize evaporation and transpiration and to prevent shoaling; by alignment; by clearing; and by guiding river flow in order to erode bars and shoals to navigable depths. Through the operation of these projects, many secondary goals such as aesthetics, fish and wildlife conservation and recreation are realized.

Quantitative data on the impact of channelization on water quality are exceedingly scarce, as indicated in Appendix E where the data base for this activity category is summarized. In addition, our data on the magnitude of channelization operations, while indicating general trends, has a major shortcoming as a basis for estimating environmental impact: it is expressed in terms of linear miles of operations (open channels, mains and laterals, etc.) rather than weight or volume of excavated material. Available data have not been adequate to permit estimation of the impact of channelization on water quality.

Nature of Effects of Channelization on Water Quality

Channel realignment, deepening, or construction of cutoffs can be designed to have the desired characteristics for producing width, depth, velocity, and optimum bend; however, biotic and hydraulic effects of such projects are not entirely understood. Upstream effects may be considerable. As a stream attempts to seek a new depth which is dictated by downstream deepening, extensive gullying may occur (See Case Study 26 in Appendix E.)

Channel modifications might also have deleterious downstream effects. The major pollutant from channelization is sediment. Depending on the amount of organic matter (trees, roots, shrubs, etc.) in the channel or on its banks, decomposition products of this material may also be present. Generally speaking, the water quality conditions existing in channelization project areas are transferred downstream to some extent, the magnitude of which depends greatly on the increased flow which might be caused by the project and by the carrying capacity of the receiving water downstream. Increasing numbers of controls put into effect on the Mississippi River have had disasterous effects on the deltaic region of coastal Louisiana. The sedimentary input to this area has been greatly decreased because of the extensive flood control and navigation improvements in the Mississippi River, and the total deltaic area is, therefore, shrinking in size. Studies indicate an average rate of loss of 16.5 square miles per year. (5-20) Even if the total sediment load of the lower Mississippi River were deposited at the delta, only 12 square miles of new land could be developed annually, which would be three quarters of the net annual loss. (5-29)

Pollutant Loads from Channelization

We have been unable to estimate present or future pollutant loads from channelization operations, either on a national or per project basis, because of inadequate data. For purposes of forecasting changes in the effects of channelization on water quality, this shortcoming may not be too important. Although we lack an absolute baseline for estimating such effects, the relative magnitude of water quality effects will probably be proportional to the relative magnitude of channelization operations. An examination of the extent of such operations over the past five years reveals no large changes with time.

The above conclusion is based on the analysis of specific soil conservation practices involving channelization as summarized in Exhibit 10, together with observations of personnel from the USDA Soil Conservation Service. Although the total number of miles of channelization for the three types of channelization practices summarized (plus a somewhat related operation--diking--that does not necessarily imply channelization) indicate a decreasing trend during

Exhibit 10. **MAGNITUDES OF AGRICULTURAL AND CONSERVATION PRACTICES INVOLVING CHANNELIZATION**(5-21)

(Entries are in Miles of Channel or Other Types of Installation)

Practices		1972	1971	1970	1969
Open Channel (mixed wet and dry excavations)	503	619	896	1,098	1,016[a]
Drainage Mains and Laterals	5,106	4,652	5,715	5,950	6,415
Irrigation Canals or Laterals	209	171	228	254	225
TOTAL MILES OF CHANNEL	5,818	5,422	6,839	7,302	7,656
Dikes	330	333	326	303	300[b]

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[a] This operational category was termed "stream channel improvement" in the statistics.

[b] This operational category was termed "dikes and levees" in the 1969 statistics.

the interval 1969-1973, this decrease is slight and probably reflects availability of funding for these specific practices during the five fiscal years considered, rather than any long-term trend in conservation practices. (5-21)

Our estimated projection of the magnitude of channelization projects for agricultural and conservation purposes for the next decade is an average of the magnitudes over the 1969-1973 period, or about 6,600 linear miles per year.

POLLUTANT LOADS FROM DREDGING

General

Most current dredging in the U. S. is for the purpose of maintaining existing navigation waterways. Approximately 300 million cubic yards of bottom material are dredged annually from rivers and other waterbodies for this purpose. An additional 80 million cubic yards are dredged in the construction of new navigation channels. These totals include 10.8 million cubic yards dredged annually from 115 lakes. To date, over 22,000 miles of waterways have been modified for commercial navigation and each year approximately 19,000 miles of waterways and 1,000 harbors are dredged in order to maintain our Nation's waterborne commerce at present levels. (5-22) Dredging is also widely used to obtain fill materials (sand and gravel) for use in construction or land reclamation.

Introduction or re-introduction of pollutants into surface waters can occur at several steps in dredging operations. When benthic material is scooped or sucked up from the streambed, some of the material can be resuspended or redissolved by the resulting turbulence. As it is lifted out of the water and loaded onto a barge for transport to a disposal site, a portion of the material is lost in the runoff. If the material is dumped into water at another location, more resuspension can occur. If it is placed on land, part of the material may be lost in surface runoff, or may leach into groundwater. Pollution also is introduced by the dredging equipment or spills of oil, grease, fuel, or lubricants. Gross quantities of material dredged and quantities placed on land or dumped into water are summarized in Exhibit 11.

Characteristics of Dredged Materials

The nature of the pollutants depends on the nature of the dredged materials. A few years ago dredging programs were undertaken to safeguard the lives of water bodies such as reservoirs and lakes without any apparent environmental pollution problem. In recent years the sediment accumulating on the bottoms of harbors and channels has become increasingly polluted as a result of effluents from industries that utilize or manufacture a variety of chemical products, and of the adoption of new kinds of fertilizers, pesticides and herbicides. As a result, the nature of the dredged material originating in such areas now ranges from clean sand and gravel to organic muck and sludge of natural origin, or to municipal and industrial waste sludges containing a variety of toxic materials. Examples of the concentration of pollutants in bottom samples is shown in Exhibit 12.

The results of studies conducted by the Kansas City Office of EPA appear in the following table of pollution parameters (Exhibit 13), with limiting concentrations establishing by EPA as a guideline for judging the state of pollution of a given sediment.

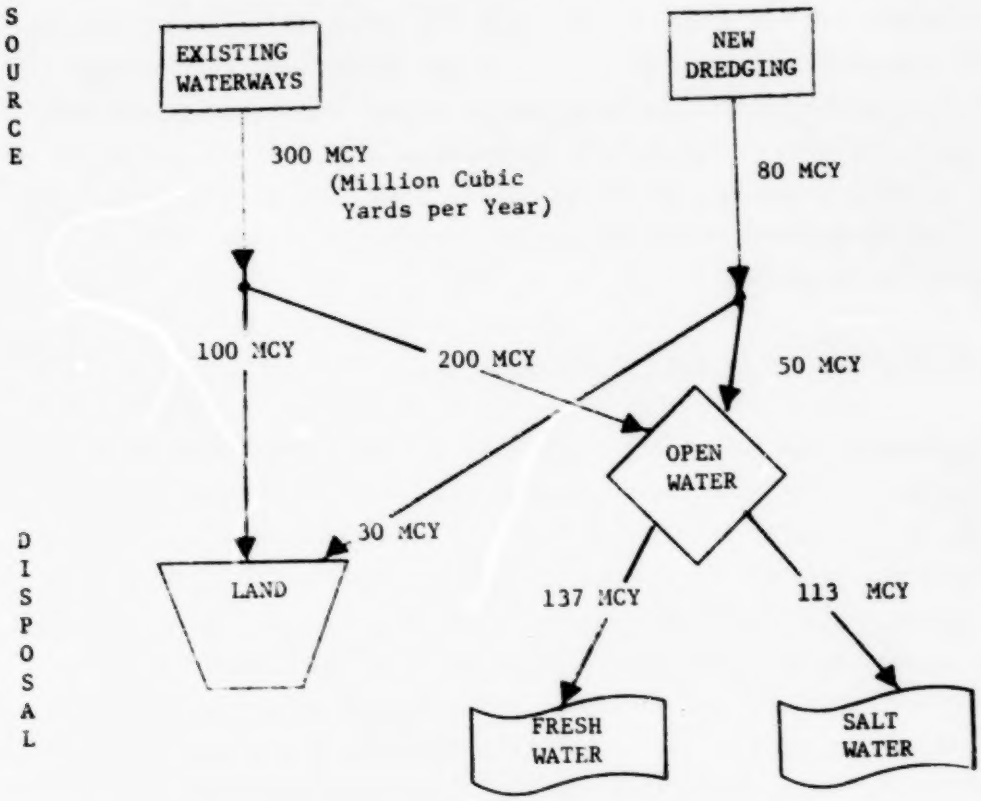
S
O
U
R
C
E
EXISTING WATERWAYS
NEW DREDGING
300 MCY (Million Cubic Yards per Year)
80 MCY
100 MCY
200 MCY
50 MCY
OPEN WATER
30 MCY
D
I
S
P
O
S
A
L
LAND
137 MCY
113 MCY
FRESH WATER
SALT WATER

Exhibit 11. Dredge Spoil Disposal Flow Chart (Estimated from Statistics Given by Boyd)(5-22)
$MCY = 10^6\ yds^3/year$

Exhibit 12. CHEMICAL COMPARISON OF SLIGHTLY AND HEAVILY POLLUTED BOTTOM SAMPLES (5-23)

Parameter	Units	Lightly Polluted		Heavily Polluted	
		Mean	Range	Mean	Range
Total Volatile Solids	%	2.9	0.7-5.0	19.6	10.2-49.3
Chemical Oxygen Demand	g/kg	21	3-48	177	39-395
Kjehldal Nitrogen	g/kg	0.55	0.01-1.31	2.64	0.58-6.80
Total Phosphorus	g/kg	0.58	0.24-0.95	1.06	0.59-2.55
Grease and Oil	g/kg	0.56	0.11-1.31	7.15	1.38-32.1
Initial Oxygen Demand	g/kg	0.50	0.08-1.24	2.07	0.28-4.65
Oxygen Uptake	g/kg				
Sulfides[a]	g/kg	0.14	0.03-0.51	1.70	0.10-3.77

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[a] Values are conservative due to preservation method used.

Exhibit 13. GUIDELINES FOR LIMITING CONCENTRATIONS OF VARIOUS POLLUTANTS IN BOTTOM SEDIMENTS (5-24)

Sediments in Fresh and Marine Waters	Concentration Percent (Dry Weight Basis)
Volatile Solids	6.0
Chemical Oxygen Demand (COD)	5.0
Total Kjeldahl Nitrogen	0.10
Oil and Grease	0.15
Mercury	0.0001
Lead	0.005
Zinc	0.005

Limited Quantitative Data on Water Quality Effects

Much of the total volume of dredging is done in close proximity to population centers, yet relatively little information is available about its effects on water quality or human health.

There is extensive literature on the problems associated with turbidity, toxicity, depletion of oxygen concentrations, and low oxygen levels, but very few studies specifically relate these problems to dredging and disposal activities or provide quantitative data about the effects on water quality. Case Studies 30 and 32 of Appendix E present data on the effects of dredging on water quality in lakes. Case Studies 28, 31, and 33 contain data on effects of dredge spoil disposal on certain water quality parameters in bays and rivers.

The authors conclude that the available data base is not adequate for making quantitative estimates of pollutant load attributable to dredging on any general basis, although some load estimates might be made for the two small lakes reported in Case Studies 30 and 32.

POLLUTANT LOADS FROM IN-WATER CONSTRUCTION

This category includes the following types of construction:

- Piledriving or placement of piers into the bottom of a water body to support over-water structures; also, the construction of structures such as docks and marinas.
- Placement of bulkheads (vertical wall) in or adjacent to a waterbody.

- Placement of structural sections (such as sections of tunnel or pipe) on the bottom of a waterbody, or in holes or ditches formed by hydraulic or mechanical means.

Nature of Water Quality Effects

No data were found on the effects of in-water construction operations on water quality. We assume that the effects are similar to those of dredging, especially for the third type of in-water construction listed above; hence, the major pollutant is resuspended sediment, with other bottom materials redissolved or resuspended in some degree. Dredging is sometimes required in the preparation of an area for in-water construction, or for obtaining fill material associated with such construction.

Extent of In-Water Construction

The data base for in-water construction (marinas, docks, bulkheads, jetties, etc.) is very sparse, both in regard to the number and magnitude of such operation and their impact on water quality. One gross indicator of the magnitude of such operations is the number of permits issued by the Army Corps of Engineers for construction in navigable waters. During the past six years, the following numbers of permits were issued: (5-25)

Fiscal Year	Number of Permits or Letters of Permission
1969	4,900
1970	5,000
1971	5,500
1972	6,500
1973	9,000
1974	15-17,000 (estimated)

The Corps anticipates issuing some 25,000 permits in FY 1975.

These statistics show a trend of increasing activity in in-water construction. This trend is probably real in view of the general increase in water-related recreational activities as well as the general increase in population; however, the actual increase is probably not as great as implied by the above tabulation for two reasons. First and most important is the fact that reporting requirements are being more stringently observed and enforced. Projects that may have been undertaken with no reporting a few years ago because they would not affect navigation must now be reported because of potential effects on water quality or other environmental parameters. The second reason is that the statistics tabulated above include permits and letters of permission for all types of projects (such as cable crossing), not only those involving in-water construction. The gross number of permits (or number of projects) does not indicate the size or type of these projects. The breakdown by size and type is maintained for each Corps of Engineers' 38 districts in the respective District Offices, but is not consolidated in any central location.(5-25), (5-26), (5-27)

Pollutant Load Data Not Available

Our survey revealed no data that would provide a basis for estimating pollutant load from in-water construction, either on a per-installation or nationwide base.

CONCURRENT AND BEGINNING STUDIES TO PROVIDE ADDITIONAL DATA

There is general recognition of the lack of quantitative information on the effects of nonpoint sources in general, and hydrologic modifications in particular, on the quality of surface water and groundwater. Research is being performed on a modest scale to develop needed information. The U. S. Environmental Protection Agency is currently sponsoring a project (being performed concurrently with the present study) by Midwest Research Institute to investigate effects of nonpoint sources, and to develop "source loading function" for major categories of sources other than construction (e.g., mining, agriculture, forestry). Within the sphere of hydrologic modifications, the preponderance of ongoing research appears in two activity categories: dredging and spoil disposal, and highway construction. Research efforts proceeding in parallel with the present study are identified in the following subsections.

Dredging and Disposal of Dredged Material

The U. S. Army Corps of Engineers' Waterways Experiment Station in Vicksburg, Mississippi, has undertaken an aggressive and broad-gauged program of research to develop better understanding of the effects of dredging on the environment and to develop means for controlling undesired effects. The program is being performed partly in-house and partly under contract. The nature of the tasks and studies included in the program is indicated by the listing of tasks appearing in a status summary of the Dredged Material Research Program (DMRP) (See Exhibit 14). Results from certain of these studies are summarized in the present report (Cases 28 and 29 of Appendix E). Some of the studies fall outside the scope of this project (for example, those concerned with ocean dumping); results of others

Exhibit 14. DREDGED MATERIAL RESEARCH PROGRAM TECHNICAL STRUCTURE(5-28)

Project/Task	Objective
Aquatic Disposal Research Project	
1A Coastal Disposal Area Field Research	Determine the magnitude and extent of effects of disposal sites on organisms and the quality of surrounding water, and the rate, diversity, and extent such sites are recolonized by benthic flora and fauna.
1B Movements of Dredged Material	Develop techniques for determining the spatial and temporal distribution of dredged material discharged into various hydrologic regimes.
1C Effects of Dredging and Disposal on Water Quality	Determine on a regional basis the short- and long-term effects on water quality due to dredging and discharging bottom sediment containing pollutants.
1D Effects of Dredging and Disposal on Aquatic Organisms	Determine on a regional basis the direct and indirect effects on aquatic organisms due to dredging and disposal operations.
1E Pollution Status of Dredged Material	Develop techniques for determining the pollutional properties of various dredged material types on a regional basis.
Habitat Development Research Project	
2A Upland and Marsh Disposal Environmental Impacts	Identification, evaluation, and monitoring of specific short-term effects and more general long-term effects of confined and unconfined disposal of dredged material on uplands, marsh, or other wetlands.
4A Artificial Marsh and Island Creation	Development, testing, and evaluation of habitat creation concepts with particular attention devoted to marsh creation and dredged material island habitats.
4B Habitat Development Research	Investigation of requirements for and technical feasibility of enhancing land and water habitats, including development and testing of wildlife-and-fisheries-oriented multiple-use concepts for confined disposal areas.
Disposal Operations Research Project	
2C Containment Area Operation Research	Development of new or improved methods for the operation and management of confined disposal areas and associated facilities.
5A Dredged Material Densification	Development and testing of promising techniques for dewatering or densifying dredged material using mechanical, biological, and/or chemical techniques prior to, during, and after placement in containment areas.
5C Disposal Area Reuse Research	Investigation of dredged material improvement and rehandling procedures aimed at permitting the removal of material from containment areas for landfill or other uses elsewhere.
6B Treatment of Contaminated Dredged Material	Evaluation of physical, chemical, and/or biological methods for the removal and recycling of dredged material constituents.
6C Turbidity Prediction and Control	Investigation of the problem of turbidity and development of a predictive capability as well as physical and chemical control methods for employment in both dredging and disposal operations.
7A Basic Equipment Related Studies	Investigation of dredging equipment modifications and improvements and operational improvements applicable to environmental impact reduction.
Productive Uses Project	
3A Aquatic Disposal Concepts Development	Investigation of environmental and economic factors involved in deepwater (oceanic) disposal, disposal in subaqueous borrow pits, and related possibilities.
3B Upland Disposal Concepts Development	Evaluation of new disposal possibilities such as using abandoned pits and mines and investigation of systems involving long-distance transport to large inland disposal facilities.
4C Land Improvement Research	Evaluation of the use of dredged material for the development, enhancement, or restoration of land for agriculture and other uses.
4D Products Research	Investigation of technical and economic aspects of the manufacture of marketable products.
5D Disposal Area Land Use Concepts	Assessment of the technical and economic aspects of the development of disposal areas as landfill sites and the development of recreation-oriented and other public or private land-use concepts.

NOTE: This technical structure reflects the first major program reevaluation made after the first full year of research accomplishment and is effective as of June 1974.

were not available at the time of preparation of the present report, although reports on several of the tasks are expected to be completed during 1974 and 1975.

Highways and Other Roads

The Utah Water Research Laboratory of the Utah State University at Logan is engaged in a project to determine effectiveness of erosion control measures applied to highway construction, and will undertake to estimate quantitatively the effects of erosion and sedimentation at a number of selected construction sites. The project, under sponsorship of the U. S. Department of Transportation, will involve visits to selected highway construction sites throughout the nation, where on-the-spot determinations will be made of the physiographic situation, climatic conditions, and specific characteristics of the construction site. Quantities of sediment eroded or deposited will be measured or estimated. Results were not available at the time of our contact with Utah State project personnel. This project, which is currently ongoing, should contribute substantially to the total information base relating site characteristics to production of sediment.(5-29)

The U. S. Geological Survey is engaged in an ongoing program of measurement of sediment and runoff from highway construction sites in the Lake Tahoe area of California.*

A study of the effects of construction of the Vail Pass on Interstate Highway I-70 in Colorado has been undertaken by several cooperating agencies, with the U. S. Forest Service (Ft. Collins

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*Information from an earlier phase of this program is reported in Case 7 of Appendix A of this report.

Office) as the principal coordinating agency. A small number of monitoring stations have been taking preconstruction measurements. The project is scheduled for completion in about five years, but data from various stages of construction should appear in the interim.(5-30)

Soils and Pollutant Runoff

The U. S. Environmental Protection Agency has recently sponsored a number of projects that bear upon the problem of sediment and other pollutant runoff from construction sites, although two of these investigations were performed in an agricultural context.

A recently issued report (5-31) (received too late to be included in the present report) concerns the movement of herbicides in runoff and on sediment from fallow plots of four types of Coastal Plain soils.

In a study for the EPA Southeastern Environmental Research Laboratory, Athens, Georgia, Hydrocomp, Inc. has developed a model for estimating pesticide transport and runoff from agricultural land on a per-event basis. The model includes a sediment subprogram based on the sediment model of Moshe Negev of Stanford University. (5-31) This type of dynamic-effects model differs sharply from the approach employed in sediment yield models such as the Universal Soil Loss Equation, which generally utilize long-term average conditions for estimating sediment yield over an extended period. The Pesticide Transport and Runoff Model has thus far been tested with the first of three years of runoff data, and is therefore considered preliminary. These tests have been based on data from the Southern Piedmont area. EPA expects to improve the model and extend its applicability to other soil types and mixed land uses.

In-Water Construction

Under sponsorship of the U. S. Army Corps of Engineers, The MITRE Corporation is currently developing loading functions for estimating the concentration and dispersion of pollutants introduced into overlying waters by such construction operations as pile driving, bulkheading, and excavation.

REFERENCES FOR SECTION V

5-1. Powell, M. D., et al., *Urban Soil Erosion and Sediment Control*, W71 02276 FWQA 15030 DTL 113P, National Assoc. of Counties Research Foundation, Washington, D.C., PB-196-111 (May 1970).

5-2. Guy, H. P., and Jones, D. E., "Urban Sedimentation in Perspective," *Journal of the Hydraulics Division*, ASCE (December 1972).

5-3. Dominick, D. D., et al., *Clean Water for the 1970's*, Federal Water Quality Administration, U.S.G.P.O., Washington, D.C. (1970).

5-4 Wolman, M. G., and Schick, A. P., "Effects of Construction on Fluvia Sediment, Urban and Suburban Areas of Maryland," *Water Resources Research*, Vol. 3, No.2 (1967).

5-5. U. S. House of Representatives Subcommittee on Appropriations, "Hearings on Department of Transportation and Related Agencies Appropriations for 1975," U.S.G.P.O. (1974).

5-6. McTavish, D., Highway Statistics Division, Federal Highway Administration, U.S. Department of Transportation, Unpublished Study Completed in 1972 (Personal Communication).

5-7. Diseker, E. G., and Richardson, E. C., "Erosion Rates and Control Methods on Highway Cuts," *Transactions*, American Society of Agricultural Engineers (1962).

5-8. *National Highway Needs Report*, U. S. Department of Transportation, Federal Highway Administration, House Document 92-266, Part 1, U.S.G.P.O., p. 5 (March 1972).

5-9. Task Committee on Urban Sedimentation Problems, *Urban Sediment Problems: A Statement on Scope*, ASCE, Committee on Sedimentation on the Hydraulics Division, p. 1301 (June 1970).

5-10. Task Committee on Preparation of Sedimentation Manual, "Sediment Sources and Sediment Yield," *Journal of the Hydraulics Division*, ASCE, p. 1301 (June 1970).

5-11. McGriff, E. C., "The Effects of Urbanization on Water Quality," *Journal of Environmental Quality*, Vol. I, No. 1, p. 87 (1972).

5-12. Soil Conservation Service, *Controlling Erosion on Construction Sites*, USDA Soil Conservation Service, Agriculture Information Bulletin 347, p. 4.

REFERENCES FOR SECTION V (Continued)

5-13. Wolman, M. G., *Problems Posed by Sediment Derived from Construction Activities in Maryland*, Maryland Water Pollution Control Commission, Annapolis, p. 49 (July 1971).

5-14. Marcin, T. C., "Protection of Demands for Housing," U.S. Department of Agriculture, Washington, D.C. (1972).

5-15. U. S. Department of Commerce, *Statistical Abstracts of the United States*, U.S.G.P.O., Washington, D.C. (July 1973).

5-16. Holeman, J. N., and Geiger, A. F., *Sedimentation of Lake Barcroft*, Fairfax County, Virginia, SCS-TP-136, Soil Conservation Service, U.S. Department of Agriculture, Washington. D.C. (March 1969).

5-17. Berkman, R. L., and Visivsi, W. K., *Damming the West*, Grossman Publishers, New York, p. 34 (1973).

5-18. McDonald, J. R., and Hyatt, R. A., "Supersaturation of Nitrogen in Water During Passage Through Hydroelectric Turbines at Mactaquac Dam," *Journal of Fisheries Research Board of Canada*, Vol. 30, No. 9 (September 1973).

5-19. "EPA Regional Office Urges Action on Nitrogen in Columbia and Snake Rivers," *Environmental Reporter*, Vol. 2, No. 21, pp. 610-611, (1971).

5-20. U.S. Army Corps of Engineering, *Report on Mississippi River Flow Requirements for Estuarine Use in Coastal Louisiana*, U.S. Army Engineer District, New Orleans, La., p. i (November 1970).

5-21. U. S. Department of Agriculture, "Status of Progress Items for Fiscal Year 1969" (plus counterpart reports for Fiscal Years 1970, 1971, 1972, 1973), Soil Conservation Service (Records Branch), Washington, D.C.

5-22. Boyd, M. B., et al., Disposal of Dredge Spoil, Technical Report H-72-8, U. S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Miss., p. 3 (November 1972).

5-23. O'Neal, G., and Sceva, J., *The Effects of Dredging on Water Quality in the Northwest*, U.S. Environmental Protection Agency, Office of Water Programs, Region X, Seattle, Washington (July 1971).

5-24. Krizek, R. J., et al., *Engineering Characteristics of Polluted Dredgings*, Technical Report No. 1, Environmental Protection Agency, p. 16 (March 1973).

REFERENCES FOR SECTION V (Continued)

5-25. Personal Communication: Capt. W. C. Allanach, Office of Dredged Material and Research, U. S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi (April 24, 1974).

5-26. Personal Communication: Mr. Eugene B. Connor, Chief, Operations Branch, Construction Operations Division, Directorate of Civil Works, Office of the Chief of Engineer, U.S. Army Corps of Engineers (October 3, 1974).

5-27. Personal Communication: Mr. James E. DeSistor, Chief Regulating Functions Branch, Directorate of Civil Works, Office of the Chief of Engineers, U. S. Army Corps of Engineer (October 3, 1974)

5-28. U. S. Army Corps of Engineers, Dredged Material Research Newsletter, Miscellaneous Paper D-74-6, Office of Dredged Material Research, Vicksburg, Mississippi (July 1974).

5-29. Personal Communication: Dr. Calvin Clyde, Utah Water Research Laboratory, Logan Utah (May 13, 1973).

5-30. Personal Communication: Mr. Bruce Perry, Nonpoint Source Division, U. S. Environmental Protection Agency, Denver, Colorado (May 6, 1973).

5-31. Crawford, N. H., and Donigan, A. S., Jr., Pesticide Transport and Runoff Model for Agricultural Lands, Hydrocomp, Inc., for U. S. EPA Southeastern Environmental Research Laboratory, Athens, Ga., EPA 660/2-74-13, Pre-publication copy, (December 1973).

SECTION VI

LOADING FUNCTIONS

The major pollutant released from construction sites is sediment. Most of the relatively small body of data collected on the release of pollutants by construction activities has concerned sediment and erosion. This is not to ignore the presence of other pollutants in construction runoff -- pesticides, nutrients, heavy metals, oil, and other components of construction wastes -- or the important work being done for estimating concentrations of such pollutants, especially in agricultural runoff. Because of the importance of the sediment problem in construction runoff and the general unavailability of data for other pollutants, the present effort to develop source loading functions has been concentrated on sediment release.

Two loading functions were fitted to sediment loss data from eight field studies of construction sites. Both are adaptations of the Universal Soil Loss Equation, and involve an empirically-fitted factor to account for effects of intervening terrain between construction site and point of sediment measurement in a nearby watercourse. Comparison of predicted sediment yields (in tons/acre) with observed yields indicates that, for one of the loading functions, about 53 percent of the predictions fall within a range of ±50 percent of observed values.

The form of the loading functions and the accuracy, limitations, and other characteristics of their predictions are discussed in the latter part of this section under the headings "Selection and Fitting of Loading Functions" and "Characteristics of Loading Function Predictions." Earlier subsections outlined the approach used in developing the functions and the history of sediment-loss model development, and describe in detail the nature and limitations of available data used to fit the loading functions.

APPROACH

Several equations for estimating sediment loss have been developed, primarily for application to agricultural land. After some experimentation with certain existing equations in which measured or estimated values of the independent variables were used to compute predicted values of sediment yield, which were then compared with observed yields, it was decided that the loading functions under development should be modifications of the Universal Soil Loss Equation, but also on the completeness, ease of use, and logical appeal of this equation

Two basic modifications of the Universal Soil Loss Equation were fitted to available data from nine separate sites where actual construction had occurred, and one additional site that contained simulated construction conditions. One of the modifications -- the "delivery-ratio approach" -- provided significantly better fit to the observed data than was given by the other modification which involved exponents arbitrarily fitted to the factors in the basic equation. Consequently, the delivery-ratio approach was selected for additional fitting.

Two variations on the delivery-ratio modification were fitted and tested. In one, the delivery ratio-factor consists of a variable "distance from construction site to receptor stream" raised to an arbitrarily-fitted exponent. In the other, the ratio factor is "percent of watershed area exposed by construction," also raised to an arbitrarily fitted exponent. The resulting two equations represent the source loading functions for out-of-stream construction activities — primarily urban construction and highways.

From the standpoint of sediment loss, the main differences between highway and urban construction are the configurations and slopes of the exposed areas. These differences can be accounted for by varying the parameters of slope length, steepness, and distance to the receptor; thus it is assumed that one type of loading function will suffice for both types of construction. This assumption is borne out, as an ititial approximation, in the analysis that follows.

HISTORY OF SEDIMENT-LOSS EQUATIONS

Equations for Agricultural Applications

Interest in the development of soil loss equations began in the early 1940's. These first equations concerned the loss from agricultural areas; most data were from the Midwest. The earliest equations were based on length and percentage of slope with factors for crop and conservation practices. In 1946 Musgrave(6-1) added a rainfall factor and reevaluated the others, producing the formula:

$$E = f\ C\ P_{30}^{1.75}\ S^{1.35}\ L^{0.35}$$

where:

- E is the net soil erosion in inches per year.
- f is a numerical value proportional to the erodibility of the soil.
- C accounted for the lack of ground cover effectiveness for erosion prevention.
- S is the percent slope.
- L is the slope length in feet.
- P_{30} is the maximum 30-minute intensity, 2-year frequency rainfall in inches. (6-2) The use of this equation was

hampered by lack of information on the influence of rainfall distribution over time, variations of soil erodibility, land cover and other factors.

In the late 1950's this equation was restructured in an improved form by Wischmeier and others working at the USDA Agricultural Research Service Center at Purdue University. This new form became known as the Universal Soil Loss Equation and is presented in detail in Reference 6-3. Its general form is:

$$A = R\ K\ L\ S\ C\ P$$

- A is the computed soil loss in tons/acre.
- R is the rainfall factor, designed to account for storm energy and intensity.
- K is the soil erodibility factor, expressing the sediment loss from a specific soil on a unit plot 72.6 feet long with a 9% slope.
- L is the slope-length factor, the ratio of soil loss from a specific slope to that from a 72.6-foot slope of similar characteristics.
- S is the slope steepness factor relating soil loss from a specific slope to that from a 9% slope.
- C is the cropping management factor, a ratio of soil loss from a field under one set of conditions to that from a field under fallow conditions.
- P is the erosion-control practice factor and compares the soil loss from contouring, strip cropping or other structural control methods to that of up-and-down slope, straight-row farming.

This equation represented a large improvement over earlier equations since it was more widely applicable and presented definite procedures for estimating the various factors. The rainfall factor was developed from individual storms$^{(6-4), (6-5)}$ and summed over the years. Average yearly values were computed for various areas and an iso-erodent map was drawn for the eastern U. S. Erosion-index distribution curves were drawn up for 33 areas of the East. These curves can be used to determine the average percent of the yearly erosion index that occurs within a specific period of a year. Further work by the Soil Conservation Service has developed several methods for estimating the rainfall index based on the 2-year, 6-hour storm and has extended it to the West Coast. This work is summarized in Reference 6-6.

The soil-erodibility factor was also improved. It was precisely defined and measured for many "bench mark" soils across the country. Wischmeier, Johnson and Cross developed a nomograph to estimate the K-factor for surface soils based on 5 parameters (soil properties such as particle size, permeability, percent organic matter, and structure).(6-8) Using this nomograph and by comparison with similar soils, the erodibilities of the various soil series are being tabulated on a state-wide basis across the country. Many states have completed estimating the values for the a, b and c horizons (upper three layers) of all their major soils. Verification of this work is continuing.

Slope length and steepness are combined into a composite term, LS, that can be read off a graph or determined by an equation. Both are normalized to a unit plot 72.6 feet long with a 9% slope.

C and P are the control factors. C accounts for the sediment reductions due to the various ground covers that may be present on a slope and P accounts for the reductions that may be due to any control structures that are present. Many lists have been compiled presenting values for different combinations of control systems.

Examples are given in References 6-3, 6-6, and 6-7.

Although the Universal Soil Loss Equation has been widely accepted for agricultural applications, some doubt exists as to its applicability to short-term activities such as construction projects, especially where steep slopes of mixed soil types are involved. The yearly rainfall erosion index, R, and the distribution curves are based on long term averages. Therefore, the shorter the time period during which construction activities expose the soil, the more likely that non-average rainfall will occur, allowing the possibility of large errors in the soil loss prediction. Questions also exist about its applicability to the West Coast and about the effects of variations in the yearly distribution of rain.

Applicability to Construction Sites

The Universal Soil Loss Equation was designed for agricultural uses, meaning generally long, regular, gentle slopes. Construction sites are usually far from regular. Highways require a reasonably gentle grade along the road bed, but the banks may be very steep. Urban construction often includes excavation, providing very steep but internally drained areas which trap the sediment eroding from their walls and even surrounding areas. Thus, the effect of these steep slopes may be to reduce the amount of sediment leaving the construction area since they can intercept and trap sediment from adjacent areas. Land areas are subject to frequent reworking so that slopes and lengths may change during construction periods. To get the best composite LS (length/steepness) term for a given construction area requires much effort in following and weighting the changes in various eroding and depositional segments of the exposed area.

It is often assumed that the topsoil is removed from a construction site and only the subsoil is exposed to erosion. Frequently, however, the topsoil is stockpiled on the site for later use. Therefore, topsoil also must be considered when determining a K factor for the "average" soil. The determinations for K factors for fitting the loading functions described later in this section involve the soil structure and permeability, as used in nomographs developed by Wischmeier et al.(6-8) During construction periods the soil is frequently moved, reshaped and compacted, posing difficult problems when using K values determined for the soils in their natural states. Another nomograph applicable to high-clay subsoils with other defined characteristics has subsequently been developed by Roth et al.(6-24) However, the 1971 Wischmeier erodibility nomographs were considered better suited for determining the K-factor for the overall range of soils included in the present study.

Transport of Sediment from Construction Site to Watercourse - The Universal Soil Loss Equation predicts the amount of soil lost or eroded from its original position and moved to the bottom of the slope, but does not account for any changes in the sediment load that may occur while it is moving towards the stream. These changes are usually in the form of deposition between the bottom of the slope and the receiving stream and can be caused by many factors, including the distance between the construction site and the receptor stream and the character of the intervening terrain - its roughness, cover, slope and shape.

Several investigators have undertaken to develop "delivery ratios" that express the fraction of material eroded that reaches the stream.(6-9), (6-10), 6-11), (6-22) The variables most often used are distance, slope, and total basin area. Of these, some combination of slope and distance appears to be the most promising, as the distance may be broken down into segments and the slope of each combined to account for any irregularity that may be present.(6-11) Most of the work that has been done in this area applies to total watersheds rather than small segments of them. Their accuracy in such situations has not been demonstrated. Guy and Jones note that there are few if any data by which a delivery ratio can be evaluated for small, rapidly changing basins undergoing development.(6-13)

A different approach used in the development of soil loss equations utilizes hydraulics and mass transport mechanics to formulate a theoretical model.(6-12) Equations in the referenced document analyze the interaction of the detachment capability of moving water and its transport capacity. This model has given encouraging results, but contains several constants that must be determined by taking specific field measurements.

Seasonal Effects -

The effects of seasons represent a possible weakness of the Universal Soil Loss Equation when applied to short-duration losses. During the winter, erosion can occur by frost movements. Most precipitation in northern areas occurs as snow. Snowfall lacks the energy of rain and causes an insignificant amount of erosion. During the spring, however, the runoff caused by snow melt often acts as a scouring agent and can remove large quantities of soil. Such processes can cause large errors in the soil loss predictions, especially in short-term projects involving the winter or spring months. Data on several of the watersheds used to fit the loading functions described in a later subsection permit comparison of predicted vs. observed soil losses during several seasons. The results are described in connection with the presentation of data for loading function development.

Other Efforts to Apply Soil Loss Equations to Construction Sites -

In addition to the above-referenced studies on delivery ratios, other investigators have recently considered the applicability of soil loss equations to construction sites. Wischmeier and Meyer illustrate the use of the soil erodibility factor and the erosion equation to predict sediment yield from construction sites, and interpret other factors in the soil loss equation relative to conditions at the site in Reference 6-21.

Meyer, Wischmeier, and Daniel report a very close comparison between a prediction by the Universal Soil Loss Equation for a given subsoil and the average of observed sediment losses under simulated rainfall losses from experimental plots shaped to simulate conditions in a construction area.(6-22) Plots were graded to 12-percent slope with surfaces scalped, scarified, or compacted-fill treatments. Close comparisons between observed sediment losses at the experimental plot and predicted losses by the Universal Soil Loss Equation were obtained in this study.

AVAILABLE DATA

There is a serious lack of field-measurement data on sediment loss and related factors for construction sites. In the present study, some 500 documents and unpublished studies were examined as potential sources of data for the various parts of this report. Forty of these were summarized and their relevant data abstracted in the case studies reported in Appendices A and B. Of these case studies, only eight were chosen to supply data for the development of loading functions for construction activities.

It must be recognized that none of the case studies were designed to supply data for developing a loading function. It could not reasonably be expected that the data reported by such a study would be perfectly suited to this purpose. Only the most complete of the available sources were chosen. Even so, many approximations of missing data had to be made. These are identified in a subsequent section on completeness of data.

Locations of Data Sources

The study sites are located in several areas of the country, but do not represent a cross-section of all conditions. Four are in the Piedmont of Maryland and Virginia. Two are in the Southern Piedmont: Georgia and North Carolina. One is in the mountains of central Pennsylvania and one is near San Francisco Bay in California. All of these studies, as well as many more that were not as useful, are summarized in Appendix A.

The most complete studies of full-scale construction sites were located near Washington, D. C., and include:

- Yorke and Davis of the U. S. Geologic Survey in the Rock Creek-Anacostia River basins in Montgomery County, Maryland, Case 14(6-13) (Case numbers refer to the study's designation in Appendix A).
- Vice, Guy and Ferguson, USGS, in the Scott Run Basin in Fairfax County, Virginia, Case 4.(6-14)
- Guy, USGS, at Kensington, Maryland, Case 9.(6-15)
- Guy and Clayton, USGS, at Reston, Virginia, Case 11.(6-16)

The other studies used were by:

- Reeder, of the USGS, in the northwestern Wake County, North Carolina, Case 1.(6-17)
- Diseker and Richardson, SCS, in Cartersville, Georgia, Case 2.(6-18)
- Reed, USGS, Pennsylvania, Harrisburg, Case 3.(6-19)

- Knott, USGS, in Colma Creek, California, Case 8.(6-20)

Completeness of Data; Parameters Reported

For purposes of loading function development, each case study would ideally include, as a minimum: descriptions of soil type, description of terrain (contours/surface soils), time-correlated measurements of rainfall, snowfall, total water runoff, sediment yield, changes in area exposed by construction activities, changes in slope of exposed areas, changes in type of soil exposed and its compaction, and changes in location of exposed areas with respect to receiving watercourse. None of the available data sources included all of these variables, although it was possible to estimate some of the missing data from maps, site layout sketches, and general engineering knowledge of the type of construction. A primary concern in the selection of case studies was to minimize the number of estimates to be made.

Since the loading functions under development were closely related to the Universal Soil Loss Equation, it was highly desirable that the case studies include data that would permit evaluation of the factors in this equation. Also, since the loading functions would probably involve a "delivery-ratio" factor based on distance between disturbed area and receiving stream or on percent of watershed disturbed, it was desirable to have measurements of these factors also. In sum, the desired variables are:

- sediment yield
- rainfall data
- soil type
- slope steepness of disturbed area
- slope length of disturbed area
- condition of disturbed surface

- type of erosion control measures (if any)
- distance of disturbed area from receiving stream
- percent of watershed disturbed by construction.

Exhibit 15 shows which of these variables were measured and reported in the eight case studies used to develop the loading functions, which were obtained from other sources, and which were estimated from site layouts or engineering judgment.

It can be seen from Exhibit 15 that most of the needed data were either provided by the author or obtained from reliable sources such as weather records or Soil Conservation Service soil maps. In only one study, Diseker/Cartersville, Georgia, was all of the needed data reported, but this was a small experimental situation although located on an actual construction site.

Soils Data -

Identification of soils were given by the authors for most of the case studies, but real distributions were given for only a few cases. For these, soil-type distribution data were obtained from the county office of the USDA Soil Conservation Service. Soil erodibility K factors were either obtained from the Soil Conservation Service and weighted according to the soil types present in the area, or they were estimated by comparison with similar soils.

Slope Steepness and Length -

Construction slopes and slope length data were generally absent from the original studies. One notable exception was the highway roadcut study in Georgia. The Rock Creek study listed slopes for one year and these were assumed constant throughout the three-year study. In general slopes were assumed to average 6% for urban construction sites and 10% for highways when no other data were given.

EXHIBIT 15. DATA FROM CASE STUDIES AND OTHER SOURCES

	Yorke & Davis Rock Creek Study			Vice, Guy, Ferguson	Guy	Guy	Reed	Diseker & Richardson	Reeder	Knott
	Lutes Run (Md)	Bel Pre Creek (Md)	Manor Run (Md)	Scott Run (Va)	Kensington (Md)	Storm Agnes (Reston, Va)	Harrisburg (Pa)	Cartersville (Ga)	I-40 (N.C.)	Colma Creek (Ca)
Sediment yield	X	X	X	X	X	X	X	X	X	X
Rainfall	X+(1)	X+(1)	X+(1)	(2)	(2)	X	(2)	X+(2)	(2)	X+(2)
Soil type	(3)	(3)	(3)	(5)	(3)	(5)	(4)	X	X	(8)
Slope steepness	0	0	0	0	0	0	0	X	0	0
Slope length	0	0	0	0	0	(6)	(6)	X	(6)	0
Surface condition	*	*	*	*	*	X	X	X	X	*
Control measures	X	X	X	*	*	X	X	X	X	*
Distance to stream	(7)	(7)	(7)	(7)	(7)	(6)	(6)	X	N A	(6)
Percent disturbed	X	X	X	X	X	X	X	X	X	X

X = Given by author of referenced source

(1) = Supplemented by raw data obtained from author

(2) = US Weather Bureau TP 40 and Wischmeier rainfall distribution

(3) = USDA Soil Conservation Service (SCS), Montgomery County, Md., Office

(4) = SCS, Harrisburg, Pa.

(5) = SCS, Fairfax Co., Va.

(6) = Estimated from site map/diagram

(7) = Estimated from SCS maps

(8) = Estimated by MITRE after consultation with SCS San Francisco office and comparison with other California soil data

N A = Not applicable; measurement taken at end of experimental plot

* = When not stated by author, surface condition was assumed to be raw cut or dense compaction with no control measure

0 = Estimated by MITRE from engineering judgement based on type of construction in given terrain

Lengths of slopes on construction sites were estimated, where appropriate, from site diagrams. Otherwise, an estimate of between 200 and 300 feet was made for urbanization construction, depending on the amount of construction in the basin and the basin size.

Slope length and steepness are combined into a composite term, LS, that can be read off a graph or determined by an equation.(6-3), (6-6) Both are normalized to a unit plot 72.6 feet long with a 9% slope.

Sediment Control Practices -

In most cases, sediment control practices were stated to be negligible. In others there may have been occasional use of hay bales or even more effective methods, but no data were given so all C and P values were assumed to equal 1.0.

Sediment from Non-Construction Sources -

In some cases, especially in the larger basins, sediment yield data were adjusted to account for non-construction sediment sources. (This adjustment was made by the author of the Colma Creek study, which was in the largest of the drainage basins considered here.) In the other studies, it was assumed that all sediment came from construction activities. This was generally a reasonable assumption since these basins were usually quite small and the agricultural activity in them was minimal or nonexistent.

Distance to Stream; Percent Area Disturbed -

Distance between construction site and receiving stream where sediment measurements were taken was generally estimated from site diagrams or maps. Since the Diseker/Georgia sediment measurements were made at the lower end of the disturbed area, data from this important source could not be applied in establishing a delivery ratio based on distance to stream.

The area disturbed by construction was given by the author in all case studies. This parameter varied during the period of construction activity, and the variation with time is given for most of the studies. From this information, the percent of the watershed disturbed by construction was computed.

Both the distance parameter and the percent area disturbed were needed for estimating the delivery ratio. The distance parameter is probably the more obvious for this purpose. The percent area parameter, while also commonly used for this purpose, was included particularly to meet the needs of a related study being performed concurrently by Midwest Research Institute.

Rainfall Data -

Rainfall and total precipitation information were given in several forms. The rainfall factor, R, was evaluated by different methods according to the form of the data. Most of the studies (Scott Run, Kensington, Harrisburg, Georgia, North Carolina, and Colma Creek) gave continuous data over periods from one month to a year. The R value for these was computed by the average annual method using the distribution curves and iso-erodent map given by Wischmeier and Smith.(6-3) For single storms where storm hydrographs were available (Rock Creek, Reston, and one storm at Kensington), R was computed by the method developed by Wischmeier as described in References 6-4 and 6-5. For other single storms where only total rainfall was available, R values were estimated using the equations given by Hotes *et al.*,(6-6) which require only total rainfall and storm duration. The latter was estimated; 24 hours most frequently gave the best results.

Rainfall data available from the Rock Creek studies of Yorke and Davis were sufficiently detailed to permit evaluation of the R factor by both of the single-storm methods referenced above. Predicted sediment yields based on both values of R are presented and compared in the subsequent presentation of data. Also, rainfall data for the Scott Run studies of Vice, Guy, and Richardson are sufficiently detailed to permit determination of separate R values for both quarterly and yearly periods. Predicted sediment yield values for these different-length periods are also compared in the following data presentation.

Presentation of Data Used to Fit Function; Sediment Yields Predicted by Universal Soil Loss Equation

The purpose of this section is to present the data used in fitting the source loading functions described in the following section. Some of the data were subjected to two types of analyses before the loading functions were fitted.

- an analysis of predicted sediment yield based on different methods of computing the rainfall factor, R.
- an analysis of predicted sediment yield for different seasons of the year.

Since both of these lines of analysis have implications for the accuracy of the loading functions, it is appropriate that they be discussed in connection with the basic data. The analysis of the effects of the methods for computing R is important since it determined the method that was subsequently used to evaluate this factor for the purpose of fitting the loading function.

Not all of the studies reported data in sufficient detail for these preliminary analyses. Only the Yorke and Davies studies of Rock Creek, Maryland, permit comparisons of different methods of computing R (after additional raw data were obtained from these authors). The Rock Creek studies and the Scott Run (Virginia) and

Kensington (Maryland) studies by Guy, Vice, and Ferguson permitted analysis of the effects of seasons.

The volume of data is large and its organization somewhat complex. The basic raw data for all case studies are presented in a single exhibit. Following this are two analytic exhibits. The first compares the effects of different methods for computing the rainfall factor on the predicted values of sediment yield, with all other factors held constant. The second shows the effects of season of the year on predicted yields.

Summary of Data from All Case Studies

The basic data from all case studies used in fitting the loading functions are tabulated in Exhibit 16. These data are used in a variety of ways in the analyses that follow, and each such application does not, in general, present all of the information available for a given site, storm event, time interval, etc. The reader who wishes to know what data went into the estimates of sediment yield presented in subsequent analytical exhibits will find the comprehensive summary of data in Exhibit 16 helpful.

In addition to basic data such as rainfall, size of construction area, slope lengths, sediment yield, etc., Exhibit 16 also contains values of the various factors of the Universal Soil Loss Equation:

R rainfall factor
K soil factor
LS slope-length factor

The computation of these factors is discussed earlier in this section. The computation of R values in Exhibit 16 were made by the method of Wischmeier and Smith(6-3), (6-5) for single storms and by the method reported in Hotes *et al.*(6-6) for cases based on

EXHIBIT 16. PRESENTATION OF BASIC DATA AND YIELDS PREDICTED BY UNIVERSAL SOIL LOSS EQUATION

Case, Location and Date	Watershed Area	% Area Disturbed by Constr	Distance to Stream	Precip.	R*	K	L	S	LS	Yield (Observed)	Yield (Predicted)**	Ratio
	acres		feet	inches			feet	%		tons/acre	tons/acre	
Yorke & Davis Rock Creek - Anacostia												
Lutes Run												
7/20/67	301	9.6	300	1.42	28.7 -S	.37	200	6.5	1.1	2.5	11.7	4.6
8/19/67		9.6		1.42	17.1 -S					1.18	6.95	5.9
10/25/67		8.3		1.14	23.3 -S					1.28	9.48	7.4
3/17/68				1.49	4.17-S					2.31	1.69	0.73
5/27/68				2.76	9.07-S					2.31	3.69	1.6
7/02/68				2.03	32.6 -S					4.08	13.23	3.2
Bel Pre Creek												
11/28/66	1082	13.9	400	1.29	5.8 -S	.35	200	5.4	.84	0.36	1.71	4.7
5/07/67		13.8		2.01	14.1 -S					1.11	4.15	3.7
7/20/67		13.6		.96	4.2 -S					0.39	1.24	3.2
8/03/67		13.4		2.28	30.0 -S					3.58	8.82	2.5
8/24-25/67		13.4		3.69	28.2 -S					3.07	8.29	2.7
6/19-20/68		9.7		1.04	17.1 -S					1.00	4.98	5.0
7/2-3/68		9.7		1.36	14.7 -S					0.50	4.32	8.6
Manor Run												
11/28/66	646	8.0	300	1.29	5.8 -S	0.36	200	7.1	1.2	0.25	2.51	10.2
5/07/67		10.8		1.98	14.1 -S					3.8	6.10	1.6
8/03/67		11		2.18	30.0 -S					6.15	12.96	2.1
8/24-25/67		11		3.28	28.2 -S					19.44	12.18	0.63
6/19-20/68		11.8		0.88	17.1 -S					6.49	7.38	1.1
7/2-3/68		11.8		1.36	14.7 -S					3.04	6.36	2.1

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* R value computed by:
S = Single storm method (Reference 3-4 and 3-5)
A = Average annual method (Reference 3-3 and 3-6)
Q = Quarterly method (Average annual method modified to quarters by Wischmeier's distribution curves. Reference 3-3.)

** By Universal Soil Loss Equation

EXHIBIT 16.

Case, Location and Date	Watershed Area	% Area Disturbed by Constr	Distance to Stream	Precip.	R*	K	L	S	LS	Yield (Observed)	Yield (Predicted)**	Ratio
	acres		feet	inches			feet	%		tons/acre	tons/acre	
Vice, Guy, Ferguson (3-14)												
Scott Run												
May - Jun '61	2900	8.6	300	7.0	50.0 -Q	0.4	250	10.0	2.5	19.4	43.0	2.2
Jul - Sep '61		10.7		11.5	100.0 -Q					18.1	86.0	4.8
Oct - Dec '61		10.3		7.25	30.0 -Q					7.84	25.8	3.3
Jan - Mar '62		10.7		9.5	12.0 -Q					11.0	10.3	0.93
Apr - Jun '62		10.5		8.5	58.0 -Q					27.3	49.9	1.8
Jul - Sep '62		9.8		4.25	100.0 -Q					0.14[x]	86.0	613.0[x]
Oct - Dec '62		8.4		11.5	30.0 -Q					10.5	25.8	2.5
Jan - Mar '63		5.5		9.5	12.0 -Q					20.9	10.32	0.49
Apr - Jun '63		3.8		9.25	58.0 -Q					21.6	49.9	2.3
Jul - Sep '63		3.6		12.5	100.0 -Q					3.2	86.0	18.8
Oct - Dec '63		2.4		9.25	30.0 -Q					16.6	25.8	1.6
Jan - Mar '64		2.1		10.5	12.0 -Q					17.3	10.3	0.6
Apr - Jun '64		1.4		7.75	58.0 -Q					16.0	49.9	3.1
Jul - Sep '64		1.9		7.00	100.0 -Q					1.82[‡]	86.0	47.3

x Only one storm reported on during quarter.
‡ Cover effects during the end of construction may have reduced this value.
(A) Sed. data is adjusted for non-const. sources - estimated by authors.

YEARLY SUMMATIONS FOR ABOVE QUARTERLY DATA FOR SCOTTS RUN

Case, Location and Date	Watershed Area	% Area Disturbed by Constr	Distance to Stream	Precip.	R*	K	L	S	LS	Yield (Observed)	Yield (Predicted)**	Ratio
1961 May - Dec	2900	10.0	300	25.75	180.0 -A	0.4	250	10.0	2.5	44.1	155	3.5
1962		9.8		33.75	200.0 -A					50.4	172	3.4
1963		3.8		40.5	200.0 -A					66.4	172	2.6
1964 Jan - Sep		1.8		25.75	170.0 -A					34.2	146	4.3
(3-16) Guy - Storm Agnes 6/72	49.1	49.1	500	13.84	283.0 -S	0.3	300	6.0	1.15	20.4	97.5	4.8

EXHIBIT 16.

Case, Location and Date	Watershed Area	% Area Disturbed by Constr	Distance to Stream	Precip.	R*	K	L	S	LS	Yield (Observed)	Yield (Predicted)**	Ratio
	acres		feet	inches			feet	%		tons/acre	tons/acre	
Guy (3-15)												
Kensington												
Jul - Sep '59	58	17.2	200	1.7	100.0 -Q	0.41	250	6.0	1.05	12.8	43.0	3.4
Oct - Dec '59		17.2		2.14	30.0 -Q					8.0	12.9	1.6
Jan - Mar '60		17.2		1.5	12.0 -Q					3.7	5.2	0.6
Apr - Jun '60.		17.2		3.1	58.0 -Q					18.4	25.0	1.4
Jul - Sep '60		17.2		8.4	100.0 -Q					45.9	43.0	0.94
Jan - Mar '61		8.6		0.4	12.0 -Q					1.2	5.2	4.3^x
Apr - Jun '61		5.2		2.12	58.0 -Q					15.0	25.0	1.7
Jul - Sep '61		1.7		1.2	100.0 -Q					6.3	43.0	6.8
Oct - Dec '61		1.7		0.5	30.0 -Q					4.4	12.9	2.9

x Only one storm reported on during quarter.

Case, Location and Date	Watershed Area	% Area Disturbed by Constr	Distance to Stream	Precip.	R*	K	L	S	LS	Yield (Observed)	Yield (Predicted)**	Ratio
Single Storm												
8/04/60	58	17.2	200	1.8	48.0 -S					25.6	20.7	0.8
(3-19) Reed-Harrisburg												
Road Const.												
May - Aug '70	490	3.1	500		58.5 -Q	0.22	300	5.0	0.95	2.7	12.2	4.6
Pond Const.												
Aug - Dec '70	490	2.2	100		58.5 -Q	0.22	350	2.0	0.4	1.6	5.1	3.2
(3-18) Diseker & Richardson												
Georgia Plot 1	0.16	69.0	0	45.28	250.0 -A	0.24	206	71.0	33.0	289.0	1973.0	6.8
Plot 3	0.21	67.0		40.1	250.0 -A	0.24	365	40.0	24.0	129.0	1286.0	10.0
Plot 5	0.15	78.0		40.1	250.0 -A	0.24	296	100.0	65.7	196	3941.0	20.0
Plot 2	0.27	67.0		45.78	250.0 -A	0.24	225	83.0	43.3	120.6	2598.0	21.6
Plot 4	0.30	67.0		40.1			310	30.0	12.6	42.8	756.0	17.7
Plot 6	0.23	65.0		40.0			321	91.0	61.0	110.1	3660.0	33.3

EXHIBIT 16.

Case, Location and Date	Watershed Area	% Area Disturbed by Constr	Distance to Stream	Precip.	R*	K	L	S	LS	Yield (Observed)	Yield (Predicted)**	Ratio
	acres		feet	inches			feet	%		tons/acre	tons/acre	
(3-17) Reeder I-40												
7/13-9/16 '71	24	83.0	800	10.01	126.0 -Q	0.45	100	20.0	4.2	67.0	238.0	35.3
9/16-2/6 '72				14.8	57.0 -Q					97.0	108.0	11.2
2/6-4/24 '72				5.85	24.0 -Q					0.68	45.4	66.7
4/24-5/8 '72				2.31	6.0 -Q					51.0	113.0	2.2
5/8-6/9 '72				4.28	21.0 -Q					58.5	387.0	6.8
6/9-7/11 '72				5.78	60.0 -Q					128.5	1134.0	8.8
7/11-8/15 '72				7.09	78.0 -Q					75.0	1474.0	19.7
(3-20) Colma Creek (Knott)												
Gaging Station												
1969	6900	14.0	2500	28.2	76.13	0.48	215	7.0	1.25	61.4 85.2	63.5	0.74x 0.53
1970		8.0	2500	19.6	76.13					41.0 66.5	44.0	1.11 0.68
1967				30.75	76.13					147.0	45.7	0.31

x Top number is author estimate of sedimente due to construction activity (not available for 1967); lower number is total measured sediment.

Single Storms												
Hickey Blvd. 2/11/69	736	42.0	500	1.2	7.6	4.8	215	7.0	1.25	1.21	4.56	3.8
Colma Creek gaging St. 2/11/69	6900	14.0	2500	1.2	7.6					1.5	4.38	2.9
Hickey Blvd. 1/20/69	736	42.0	500	0.5	1.1					0.56	0.67	1.2
Colma Creek 1/20/69	6900	14.0	2500	0.5	1.1					0.68	0.66	0.96
Avalon 1/20/69	211	20.0	500	0.1	1.1					10.0	0.66	0.07

continuous records for quarterly or annual periods.

Method of Comparison: Ratio of Predicted-to-Observed Sediment Loss - The basic parameter to be estimated by the loading functions is quantity of sediment reaching the receiving water per unit of area disturbed by construction. The unit is tons/acre. In order for a case study to be useful for developing loading functions, one or more measured values of this parameter must be reported. Such values may be for a single-storm event or for defined time intervals.

As a means of coarsely assessing the effects of seasonal variations or of methods of computing the rainfall factor on the predictive capability of loading functions, the Universal Soil Loss Equation was used to "predict" the sediment loss for each storm event or time interval for which sediment-loss measurements were available. The results were compared with measured (or "observed") values, and a ratio of predicted/observed values computed. This ratio forms the basic unit of comparison used in this section of the report. A similar ratio based on "predicted" values from fitted loading functions is used in a later section for evaluating the accuracy of these functions. (A ratio value of 1.0 would indicate perfect agreement between predicted and observed yields.)

The Universal Soil Loss Equation was chosen for these preliminary analyses because it appeared to be the most nearly applicable model available, prior to the development of actual loading functions based on the data at hand, but primarily because the investigators anticipated that the loading functions would be variations of this equation.

Comparison of Two Methods for Computing R For Single Storms - The rainfall data for the Rock Creek/Anacostia River studies of

Yorke and Davies were sufficiently complete when augmented by raw data from the authors) to permit computation of the rainfall factor R needed in the Universal Soil Loss Equation by two different methods: one developed by Wischmeier and Smith(6-3), (6-5) and a newer procedure reported in 1973 by Hotes et al.(6-6) The resulting values of R in the Exhibit are designated as R_1 and R_2.

R- values were computed by both methods, and predicted sediment yield per acre during each storm was computed by the Universal Soil Loss Equation for each value of R. Results are given in Exhibit 17.

To facilitate comparison, the ratio of predicted/observed yield was computed for each R-value, and these ratios were averaged for all storm events. Comparison of the two columns of ratios near the right hand side of the exhibit reveals considerable divergence in the results obtained from the two R-values, and these ratios were averaged for all storm events. Comparison of the two columns of ratios near the right hand side of the exhibit reveals considerable divergence in the results obtained from the two R-values, although the averages of ratios are similar for the two methods: 3.8 for R_1 and 3.6 for R_2. The range of ratio values for R_1 is smaller than the range for R_2.

Although the smaller average value of ratios for R_2 might be interpreted to mean that R_2 provides a slightly more accurate prediction (in the sense that predicted values agree more closely with observed); the two averages were so close that the difference was considered not to be significant. Also, the scatter (range of ratio values) for R_1 was somewhat smaller than for R_2.

In view of these results, neither method was judged clearly

EXHIBIT 17. TWO METHODS FOR ESTIMATING RAINFALL EFFECTS

Case, Location and Date	Precipitation	R_1 (by Ref. (3-3),(3-5))	R_2 (by Ref. 3-6	Yield (Observed)	Based on R_1		Based on R_2	
					Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed
	inches			tons/acre	tons/acre		tons/acre	
Yorke & Davis Rock Creek-Anacostia								
Lutes Run								
7/20/67	1.42	28.7	9.4	2.5	11.7	4.6	3.84	1.5
8/19/67	1.42	17.1	9.4	1.18	6.95	5.9	3.84	3.3
10/25/67	1.14	23.3	8.0	1.28	9.48	7.4	3.26	2.5
3/17/68	1.49	4.17	16.7	2.31	1.69	0.73	6.77	2.9
5/27/68	2.76	9.07	53.7	2.31	3.69	1.6	21.85	9.5
7/02/68	2.03	32.6	20.7	4.08	13.23	3.2	8.42	2.1
Bel Pre Creek								
11/28/66	1.29	5.8	7.64	0.36	1.71	4.7	2.2	6.2
5/7/67	2.01	14.1	20.3	1.11	4.15	3.7	6.0	5.4
7/20/67	0.96	4.2	4.0	0.39	1.24	3.2	1.2	3.0
8/3/67	2.28	30.0	26.8	3.58	8.82	2.5	7.9	2.2
8/24-25/67	3.69	28.2	77.1	3.07	8.29	2.7	22.6	7.4
6/19-20/68	1.04	17.1	4.8	1.00	4.98	5.0	1.4	1.4
7/2-3/68	1.36	14.7	8.6	0.50	4.32	8.6	2.5	1.5
Manor Run								
11/28/66	1.29	5.8	7.64	0.25	2.51	10.2	3.3	13.2
5/7/67	1.98	14.1	19.6	3.8	6.10	1.6	15.5	2.1
8/3/67	2.18	30.0	24.3	6.15	12.96	2.1	10.4	1.7
8/24-25/67	3.28	28.2	59.5	19.44	12.18	0.63	25.6	1.3
6/19-20/68	0.88	17.1	6.3	6.49	7.38	1.1	2.7	0.42
7/2-3/68	1.36	14.7	8.6	3.04	6.36	2.1	3.7	1.2
					Average	3.8	Average	3.6

preferable to the other. If the time distribution of rainfall during the storm is available, as in the Rock Creek studies, the R_1 approach is preferred by the present authors. If this information is not available, the R_2 approach should be used since it requires only a knowledge of total rainfall during the storm and an estimate of storm duration.

The R_1 procedure, based on the method of Wischmeier and Smith, was selected for subsequent analyses of single storm data, including the fitting of loading functions.

Effects of Seasons on Predictive Capability - Preliminary analysis of the predicted-to-observed ratios in Exhibit 16 revealed a cyclic pattern with season for the four case studies reporting seasonal data. Relevant data from these four studies were abstracted and compiled in Exhibit 18 to show the seasonal effect.

Predicted values of sediment yield rates for measures made during the winter were generally equal to or lower than the observed yield rates, while in the spring and fall the predicted values averaged 3 to 5 times higher than the observed, and in the summer averaged 6 to 7 times higher. The average of predicted-to-observed ratios for the quarterly periods shown in Exhibit 18 are as follows.

Quarter	Ratio Average
January - March	1.3
April - June	2.5
July - September	6.5
October - December	4.2

The interpretation of these results is by no means clear. The

EXHIBIT 1 . COMPARISON OF THE EFFECTS OF SEASONAL VARIATIONS ON SEDIMENT YIELD

Case, Location and Date	Precip.	R/Method	Yield (Observed)	Yield (Predicted)	Ratio Predicted/ Observed
	inches		tons/acre		
			JANUARY - MARCH		
Lutes Run					
3/17/68	1.49	4.17-S	30	22	.73
Scott Run '62	9.5	12 -Q	3475	3200	.93
'63	9.5	12 -Q	3350	1651	.49
'64	10.5	12 -Q	1040	619	.6
Kensington '60	1.5	12 -Q	87.3	51.6	.6
'61	.4	12 -Q	6	26	4.3
				Average	1.3
			JULY - SEPTEMBER		
Lutes Run					
7/20/67	1.42	28.7 -S	73	337	4.6
8/19/67	1.42	17.1 -S	34	201	5.9
7/02/68	2.03	32.6 -S	53	172	3.2
Bel Pre Creek					
7/20/67	.96	4.2 -S	57	182	3.2
8/03/67	2.28	30.0 -S	519	1,279	2.5
8/24-25/67	3.69	28.2 -S	445	1,202	2.7
7/2-3/68	1.36	14.7 -S	53	458	8.6
Manor Run					
8/3/67	2.18	30.0 -S	437	920	2.1
8/24-25/67	3.28	28.2 -S	1380	865	0.63
7/2-3/68	1.36	14.7 -S	231	483	2.1
Scott Run '61	11.5	100 -Q	4844	10,750	2.2
'62	4.25	100 -Q	40	24,510	613*
'63	12.5	100 -Q	480	9,030	18.8
' 64	7.0	100 -Q	100	4,730	47.3
Kensington '59	1.7	100 -Q	128	430	3.4
'60	8.4	100 -Q	459	430	0.94
'61	1.2	100 -Q	6.3	43	6.8
8/4/60	1.8	48 -S	256	207	0.8
				Average	6.5

* One storm

Case, Location and Date	Precip.	R/Method	Yield (Observed)	Yield (Predicted)	Ratio Predicted/ Observed
	inches		tons/acre		
			APRIL - JUNE		
Lutes Run					
5/27/68	2.76	9.07-S	30	48	1.6
Bel Pre Creek					
5/7/67	2.01	14.1 -S	165	618	3.7
5/19-20/68	1.04	17.1 -S	106	528	5.0
Manor Run					
5/7/67	1.98	14.1 -S	264	426	1.6
6/19-20/68	0.88	17.1 -S	493	561	1.1
Scott Run					
May-June '61	7.0	50 -Q	4,844	10,750	2.2
'62	8.5	58 -Q	8,330	15,213	1.8
'63	9.25	58 -Q	2,380	5,847	2.3
'64	7.75	58 -Q	640	1,995	3.1
Guy-Agnes					
6/72	13.84	283 -S	492	2,351	4.8
Kensington '60	3.1	58 -Q	184	250	1.4
'61	2.12	58 -Q	44	75	1.7
				Average	2.5
			OCTOBER - DECEMBER		
Lutes Run					
10/25/67	1.14	23.3 -S	9.48	1.28	7.4
Manor Run					
11/28/66	1.29	5.8 -S	2.31	0.23	10.2
Scott Run					
Oct-Dec '61	7.25	30 -Q	25.8	7.84	3.3
'62	11.5	30 -Q	25.8	10.5	2.5
'63	9.25	30 -Q	25.8	16.6	1.6
Kensington					
Oct-Dec '59	2.14	30 -Q	12.9	8	1.6
'61	0.5	30 -Q	12.9	4.4	2.9
				Average	4.2

apparent seasonal differences may indicate unusual rainfall patterns during the study periods or it may mean the distribution curves for these areas need adjustment. The Kensington study results may appear misleading because only selected storm results were reported, totaling less than one-half the yearly precipitation. Presumably most of the large storms are reported, since the results are similar to those from the other areas in the vicinity.

All of the case studies covered in Exhibit 18 are located in close proximity to one another -- all lie in the Washington, D. C., metropolitan area. The results, therefore, cannot be considered generally applicable to other areas. While data from the other case studies in this report are not adequate for including season-related effects in loading functions developed in the present study, the patterns shown in Exhibit 18 appear sufficiently definite to suggest that season-related effects should be investigated in subsequent research on sediment yield prediction.

One Missing Case: Germantown, Maryland, Residential Development Study -

A relatively new source of data in which essentially all of the needed parameters were recorded was the development of a residential subdivision above Gunner's Branch near the Village of Germantown in Montgomery County, Maryland. Records of suspended sediment concentration and rainfall are available over a period of several years (1971-1974), during which time the development occurred. Amount of disturbed area during each of the three phases of development (1973-1974) is available. Detailed site maps indicate slopes and can be used to determine distance to waterways. Good soil data are available.

Unfortunately, this information could not be used for fitting the functions because it came to the attention of the study team too late to permit reduction of the meteorological and hydrologic data, most of which are in the form of stripcharts and other unreduced records. Although no formal study of these records has been made, they are written up as a "case study" (Number 18) in Appendix A to indicate the completeness of available data, both reduced and unreduced.

SELECTION AND FITTING OF LOADING FUNCTIONS

The endeavor to develop sediment yield loading functions began early in this study with experiments in fitting established soil loss models to the available data, then comparing computed yields with observed to assess the fit. Models tested included established soil loss equations such as the Musgrave* and the Universal Soil Loss Equation*, as well as some arbitrary functions proposed by the investigators. The latter were of the general form of the Musgrave Equation: multiplicative factors raised to powers, but with the additional feature of additive constants.

From the standpoint of estimating observed sediment yields, the Universal Soil Loss Equation proved generally superior to the other forms tested, to the extent that the investigators decided to concentrate on modifying this basic equation to improve its fit to construction-related data. Two types of modifications were evaluated.

One modification set the C and P values (cropping and erosion control factors) to unity, added a distance factor, D (average distance of overland travel from construction area to receptor stream), and fitted empirically-determined exponents to the three terrain-related factors to produce a new equation of the form:

---

*See the Approach subsection presented earlier for a more complete description of these equations.

$$Y = RKL^a S^b D^c$$

where Y is sediment yield in tons/acre and the other factors are as they appear in the universal and the Musgrave, and with its exponential modification to slope and slope length, appears to provide the flexibility needed for adaptation to construction conditions. However, when the exponents were fitted to observed data by the method of least squares, the resulting function gave predicted yields that compared less closely with observed yields than did the predictions of the Universal Soil Loss Equation. This result is ambiguous at best, since the above equation with three arbitrarily-fitted constants should theoretically have given at least as close a fit as the deterministic Universal Soil Loss Equation. This ambiguity was attributed to sparse data of unknown reliability, and the above equation was abandoned in favor of a simpler formulation bearing a close relation to the Universal Soil Loss Equation.

The simpler form of model tested next was the basic Universal Soil Loss Equation adjusted by a "delivery ratio" to account for the difference in total sediment yield at the site and the amount reaching the receptor stream. The concept of a delivery-ratio has been suggested and applied by several investigators,(6-4), (6-10), (6-11), (6-22) but to our knowledge the forms of this factor used in the present study and their application to construction-site data have not previously been investigated. The resulting equation is of the form:

$$Y = R\ K\ LS\ C\ P\ (Z)^x$$

where $(Z)^x$ is the delivery ratio and other elements are the elements of the Universal Soil Loss Equation as defined above.

Two intuitively relevant parameters that could be evaluated for most of the case studies were chosen as the Z variable in the delivery-ratio:

D - distance between construction site and receptor stream

%A - percent of drainage basin exposed by construction

Observed values for these two parameters were used in obtaining a least square fit for the exponent x. (The factors C and P were again set to unity but were retained in the resulting equation.) The resulting functions were obtained:

$$Y = R\ K\ LS\ C\ P\ D^{-0.22}$$

$$Y = R\ K\ LS\ C\ P\ (\%A)^{-0.51}$$

These two equations were considered by the investigators to be the best sediment loading functions readily obtainable from the available data.

Results obtained by applying these loading functions to the data from all case studies are presented in Exhibit 19. Sediment yield rates obtained from each function are expressed as ratios to the observed rates. To facilitate comparison, these ratios are displayed together with the predictions obtained from the Universal Soil Loss Equation and with values of certain critical parameters that enter into the yield calculations.

CHARACTERISTICS OF LOADING FUNCTIONS PREDICTIONS

The sediment yield rate predicted by an equation such as the Universal Soil Loss Equation refers to the condition at the boundary of the area in question, whether this contains agricultural lands or construction. The predicted rate might logically be expected to be lower than the rate observed some distance away in a watercourse. This expectation is borne out in the Exhibit 19 data, which shows predicted/observed ratios for the Universal

EXHIBIT 19. COMPARISON OF FITTED FUNCTIONS

Case, Location and Date	Method of Computing R	Watershed Area	% Area Disturbed by Constr	Distance to receptor stream	Yield (Observed)	By Universal Soil Loss Equation		By Loading Function Adjusted For Distance to Stream		By Loading Function Adjusted For % Area Disturbed	
						Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed
		acres		feet	tons/acre						
(3-13) Yorke & Davis Rock Creek- Anacostia											
Lutes Run											
7/20/67	S	301	9.6	300	2.5	11.7	4.6	3.3	1.3	3.6	1.45
8/19/67			9.6		1.18	6.95	5.9	2.0	1.7	2.2	1.86
10/25/67			8.3		1.28	9.48	7.4	2.7	2.1	3.2	2.5
3/17/68					2.31	1.69	0.73	0.5	0.21	0.8	0.34
5/27/68					2.31	3.69	1.6	1.1	0.46	1.8	0.76
7/02/68					4.08	13.23	3.2	3.8	0.92	6.2	1.52
Bel Pre Creek											
11/28/66	S	1082	13.9	400	0.36	1.71	4.7	0.47	1.3	0.44	1.23
5/07/67			13.8		1.11	4.15	3.7	1.1	0.99	1.1	0.97
7/20/67			13.6		0.39	1.24	3.2	0.33	0.85	0.33	0.85
8/03/67			13.4		3.58	8.82	2.5	2.4	0.66	2.4	0.67
8/24-25/67			13.4		3.07	8.29	2.7	2.2	0.72	2.2	0.72
6/19-20/68			9.7		1.00	4.98	5.0	1.3	1.34	1.6	1.57
7/2-3/68			9.7		0.50	4.32	8.6	1.2	2.3	1.4	2.7
Manor Run											
11/28/66	S	646	8.0	300	0.25	2.51	10.2	0.73	2.9	0.88	3.53
5/07/67			10.8		3.8	6.10	1.6	1.7	0.46	1.7	0.46
8/03/67			11.0		6.15	12.96	2.1	4.9	0.80	3.8	0.62
8/24-25/67			11.0		19.44	12.18	0.63	3.5	0.18	3.7	0.19
6/19-20/68			11.8		6.49	7.38	1.1	2.0	0.31	2.0	0.31
7/2-3/63			11.8		3.04	6.36	2.1	1.8	0.60	1.8	0.60

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EXHIBIT 19.

Case, Location and Date	Method of Computing R	Watershed Area	% Area Disturbed by Constr	Distance to receptor stream	Yield (Observed)	By Universal Soil Loss Equation		By Loading Function Adjusted For Distance to Stream		By Loading Function Adjusted For % Area Disturbed	
						Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed
		acres		feet	tons/acre						
Guy (3-15)											
Kensington											
Jul - Sep '59	Q	58	17.2	200	12.8	43.0	3.4	64.8	1.06	10.2	0.80
Oct - Dec '59			17.2		8.0	12.9	1.6	4.0	0.50	3.0	0.37
Jan - Mar '60			17.2		8.7	5.2	0.6	1.7	0.44	1.2	0.14
Apr - Jun '60			17.2		18.4	25.0	1.4	8.1	0.44	6.1	0.33
Jul - Sep.'60			17.2		45.9	43.0	0.94	13.3	0.29	10.1	0.22
Jan - Mar '61			8.6		1.2	5.2	4.3x	1.6	1.34	1.7	1.4
Apr - Jun '61			5.2		15.0	25.0	1.7	7.9	0.53	109.5	7.3
Jul - Sep '61			1.7		6.3	43.0	6.8	13.6	2.12	32.7	5.2
Oct - Dec '61			1.7		4.4	12.9	2.9	4.0	0.90	9.7	2.2
x Only one storm reported on during quarter.											
Single Storm											
8/4/60	S	58	17.2	200	25.6	20.7	0.8	5.2	0.25	3.9	0.19
(3-19) **Reed-Harrisburg**											
Road Const.											
May - Aug '70	Q	490	3.1	500	2.7	12.2	4.6	3.2	1.17	7.0	2.6
Pond Const.											
Aug - Dec '70	Q	490	2.2	100	1.6	5.1	3.2	1.9	1.16	33.6	21.0
(3-18) **Diseker & Richardson**											
Georgia Plot 1	A	0.16	69.0	0	289.0	1973.0	6.8	3266.0	Not Applicable	225.0	0.78
Plot 3	A	0.21	67.0		129.0	1286.0	10.0	2167.0		151.0	1.17
Plot 5	A	0.15	78.0		196.0	3941.0	20.0	6507.0		423.0	2.16
Plot 2	A	0.27	67.0		120.6	2598.0	21.6	2605.0		305.0	2.53
Plot 4	A	0.30	67.0		42.8	756.0	17.7	608.0		42.8	1.00
Plot 6	A	0.23	65.0		110.1	3660.0	33.3	3017.0		216.0	1.96

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EXHIBIT 19.

Case, Location and Date	Method of Computing R	Watershed Area	% Area Disturbed by Constr	Distance to receptor stream	Yield (Observed)	By Universal Soil Loss Equation		By Loading Function Adjusted For Distance to Stream		By Loading Function Adjusted For % Area Disturbed	
						Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed
		acres		feet	tons/acre						
Vice, Guy, Ferguson (3-14)											
Scott Run											
May - Jun '61	Q	2900	8.6	300	19.4	43.0	2.2	12.2	0.63	14.2	0.73
Jul - Sep '61			10.7		18.1	86.0	4.8	24.8	1.37	25.9	1.43
Oct - Dec '61			10.3		7.84	25.8	3.3	7.4	0.94	7.8	1.0
Jan - Mar '62			10.7		11.0	10.3	0.93	3.0	0.27	3.1	0.28
Apr - Jun '62			10.5		27.3	49.9	1.8	13.9	0.51	14.7	0.54
Jul - Sep '62			9.8		0.14x	86.0x	613.0x	24.5	174.8x	27.0	191.4x
Oct - Dec '62			8.4		10.5	25.8	2.5	7.5	0.71	8.8	0.84
Jan - Mar '63			5.5		20.9	10.32	0.49	2.9	0.14	4.4	0.21
Apr - Jun '63			3.8		21.6	49.9	2.3	14.3	0.66	25.1	1.16
Jul - Sep '63			3.6		3.2	86.0	18.8	17.2	5.36	31.4	9.8
Oct - Dec '63			2.4		16.6	25.8	1.6	7.6	0.46	16.9	1.02
Jan - Mar '64			2.1		17.3	10.3	0.6	2.9	0.17	7.1	0.41
Apr - Jun '64			1.4		16.0	49.9	3.1	14.1	0.88	41.8	2.61
Jul - Sep '64			1.9		1.82‡	86.0	47.3	24.6	13.49	62.1	34.1
YEARLY SUMMATIONS FOR ABOVE QUARTERLY DATA FOR SCOTTS RUN											
1961 May - Dec	A	2900	10.0	300	44.1	155.0	3.5	44.1	1.0	48.5	1.1
1962			9.8		50.4	172.0	3.4	48.9	0.97	53.4	1.06
1963			3.8		66.4	172.0	2.6	49.1	0.74	86.3	1.3
1964 Jan - Sep			1.8		34.2	146.0	4.3	42.1	1.23	109.4	3.2
(3-16) Guy - Storm Agnes 6/72	S	49.1	49.1	500	20.4	97.5	4.8	28.6	1.4	13.3	0.65

x Only one storm reported on during quarter.

‡ Cover effects during the end of construction may have reduced this value.
(A) Sed. data is adjusted for non-const. sources - estimated by authors.

EXHIBIT 19.

Case, Location and Date	Method of Computing R	Watershed Area	% Area Disturbed by Constr	Distance to receptor stream	Yield (Observed)	By Universal Soil Loss Equation		By Loading Function Adjusted For Distance to Stream		By Loading Function Adjusted For % Area Disturbed	
						Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed
		acres		feet	tons/acre						
(3-17) **Reeder I-40**											
7/13-9/16 '71	Q	24.0	83.0	800	67.0	238.0	3.5	54.7	0.82	25.0	0.37
9/16-2/6 '72					97.0	108.0	1.1	24.8	0.26	11.3	0.12
2/6-4/24 '72					0.68	45.4	66.7	10.4	15.3	4.8	7.0
4/24-5/8 '72					51.0	113.0	2.2	26.0	0.51	11.9	0.23
5/8-6/9 '72					58.5	387.0	6.8	88.9	1.52	40.6	0.69
6/9-7/11 '72					128.5	1134.0	8.8	261.	2.0	119.	0.93
7/11-8/15 '72					75.0	1474.0	19.7	339.	4.5	155.	2.03
(3-20) **Colma Creek** (Knott)											
Gaging Station											
1969	A	6900	14.0	2500	61.4^{x} 85.2	45.7	0.74^{x} 0.53	11.1^{x} 15.3	0.18	16.0^{x} 22.1	0.26
1970	A		8.0		41.0 66.5	44.0	1.11 0.68	7.8 12.6	0.19	15.2 24.6	0.37
1967	A		NA		147.0	45.7	0.31				
Single Storms											
Hickey Blvd. 2/11/69	S	736	42.0	500	1.21	4.56	3.8	1.3	1.1	0.7	0.56
Colma Creek gaging St. 2/11/69	S	6900	14.0	2500	1.5	4.38	2.9	0.8	0.52	1.3	0.75
Hickey Blvd 1/20/69	S	736	42.0	500	0.56	0.67	1.2	0.2	0.4	0.1	0.18
Colma Creek 1/20/69	S	6900	14.0	2500	0.68	0.66	0.96	0.1	0.17	0.2	0.25
Avalon 1/20/69	S	211	20.0	500	10.0	0.66	0.07	0.3	0.03	0.2	0.02
AVERAGE OF RATIO VALUES FOR ALL CASE STUDIES							7.37		1.33		1.78

x Top number is author estimate of sediments due to construction activity (not available for 1967); lower number is total measured sediment.

Equation as generally greater than unity, the average value being 7.37. In contrast, L. D. Meyers(6-22) reports a value very close to unity (0198) at the foot of an experimental plot. This difference is probably due, in part, to the effects of intervening terrains.

The improvement in predictive capability of the two fitted loading functions relative to the Universal Equation for construction sites is indicated by the generally lower values of the predicted/observed ratio values for the loading functions. The average values over all case studies are as follows:

	Average Value of Ratio
Universal Soil Loss Equation	7.37
Loading function with adjustment for distance	1.33
Loading function with adjustment for percent of watershed area disturbed	1.78

The reader is reminded that the above values are averages of ratios of predicted (or estimated) yields in tons/acre to observed yields in the same unit. Thus a ratio of 1.00 indicates that the estimated and observed values are equal.

Averages, Standard Deviations, and Frequency Distributions of Predicted/Observed Ratios

It is with some reluctance that the writers report summary statistics (averages, ranges, standard deviations) of the yield ratios because of difficulties in interpretation of these statistics and the potential for misapplication.

One problem of interpretation is in the meaning of an average of ratios. Given the method of computing ratios used in this report, the values cannot be negative. Any estimate less than the corresponding observed yield produces a ratio value between zero and unity; any estimate greater than the observed yield produces a value greater than unity -- sometimes much greater since it is not constrained by an upper bound as in the case of the less-than-observed ratio. If, for example, an estimated value is one-fifth the observed, the ratio is 0.20. If it is five times greater, the value is 5.00. The average of these two ratio values is 2.60, implying that "on the average" the predicted values are 2.6 times greater than observed. From one standpoint, the average appears unduly weighted by the large ratio values when the estimate exceeds the observed value. This weighting effect is similarly reflected in measures of scatter such as the range or standard deviation.

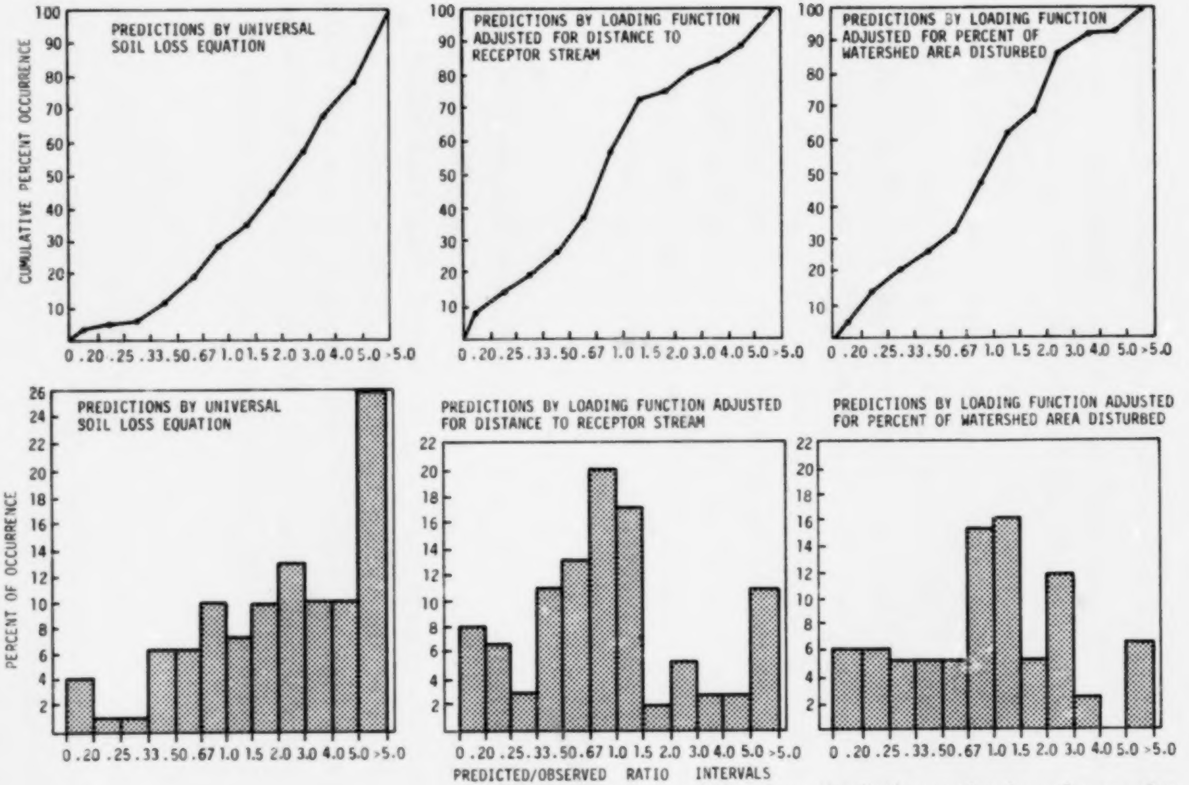
With the above observations and caveats, the summary statistics of the yield ratios for values predicted by the Universal Soil Loss Equation and the two loading functions are given in Exhibit 20. In presenting these results, the authors emphasize that the statistics have not been subjected to thorough analysis evaluation, and therefore are not recommended for use in testing of hypotheses concerning closeness of fit of predicted-to-observed yields or similarity among results predicted by the three methods.

Perhaps more revealing and more easily interpreted than the summary statistics are the frequency distributions of ratios presented in Exhibit 21. As expected, the predictions by the Universal Soil Loss Equation tend generally to overestimate the sediment yield, because of the effects of terrain between disturbed area and point of measurement. Additional analysis of the large percent of cases with ratios greater than 5.0 might reveal a more nearly symmetric tailing off of these higher estimates by the

Exhibit 20. MEANS AND STANDARD DEVIATIONS OF PREDICTED/OBSERVED RATIOS OBTAINED BY THREE ESTIMATING PROCEDURES

•	By Universal Soil Loss Equation	By Loading Function Adjusted for Distance to Stream	By Loading Function Adjusted for % Area Disturbed
Average of All Ratio Values*	7.37	1.33	1.78
Standard Deviations	11.20	2.23	3.09
Number of Observations* in above statistics	53	47	53

*For Scott Run, only annual averages were used, and the storm during quarter of July-September 1962 was excluded. For Colma Creek, only single storm results were used.



(NOTE: These distributions are based on a larger number of ratio values than the statistics in Exhibit 20, since quarterly and yearly estimates are included in the histograms.)

EXHIBIT 21
PERCENT FREQUENCY DISTRIBUTIONS OF PREDICTED/OBSERVED RATIOS

Universal Equation. This line of analysis was not pursued since our primary interest is in the fitted loading functions.

The frequency distribution for the loading function adjusted for distance between disturbed area and receptor stream exhibits a definite clustering near the ratio value of 1.00, and shows a general symmetry about this value. Instead of tailing off at either extreme, however, it displays a clustering at the extremes. In this distribution, approximately 53 percent of the yield ratios lie between values of 0.50 and 1.50, implying that 53 percent of the estimated yields fell within ±50 percent of the observed. Also, about 90 percent of the values lie between 0.20 and 5.00, implying that 90 percent of the estimated yields fall within one-fifth and five times the observed value. The median lies in the interval 0.67-1.00. These percentage intervals and ranges are based on the case studies of this report, and should not be considered universally applicable.

The function adjusted for percent of basin area disturbed by construction also exhibits a clustering about the ratio value of 1.0. The distribution appears generally symmetric about this value. Some 30 percent of the values lie within the ratio range of 0.50 to 1.50, implying that 30 percent of the estimated values fall within 50 percent of observed. Also, about 84 percent of the ratios lie between 0.20 and 5.00. The median lies between ratio values of 1.01 and 1.50.

It should be noted that the ratio intervals used in forming these distributions are arbitrary and highly non-uniform. Intervals for values less than unity are arbitrarily based on the fractions 1/5, 1/4, 1/3, 1/2, and 2/3 while those greater than unity are 1.5, 3, 4, and 5. If unit intervals between 0 and 5 had been used, roughly half of the observations would have been in the 0-1 interval for both of the fitted functions. This arrangement would have provided little detail about the low estimates.

Accuracy of the Loading Functions; Generality of Application

There are three general conditions that must be weighed and taken into account when considering whether the fitted loading functions should be used to estimate sediment yield for areas other than those used to develop the study.

First, the potential user should recognize that the soil type, terrain, and rainfall patterns of the case study sites are not entirely general for the United States. In particular, the Great Plains and Western Mountain areas are not included. Nevertheless, the studies do include a substantial variety of soil types and terrain features, and the importance of such a variety should not be minimized.

Second, the functions were developed from available data from the literature rather than from experiments designed specifically for this purpose, and the results did not lend themselves readily to straight-forward statistical analysis. The level of analysis performed thus far has not been sufficiently detailed to permit testing of hypotheses or setting confidence limits on the accuracy of estimates. Possibly, further analysis of the data in Exhibits 19 and 21 may produce these types of results.

Third, and on the optimistic side of the picture, few if any models for predicting sediment yield from construction sites have been examined and analyzed to the extent of the loading functions developed in this report. For computing sediment reaching a watercourse some distance from the disturbed area under the range of conditions defined in the case studies, the superiority of these loading functions to the Universal Soil Loss Equation seems intuitively apparent (although not statistically proven) from the frequency distributions in Exhibit 21.

In summary, the authors conclude that the loading functions developed here provide the best available means for predicting the sediment yield from a construction site, in the absence of specific yield data for that site. This conclusion is based on an extensive review of the literature as well as the foregoing analysis of data. Although no solid statistical basis has been developed for assessing the accuracy of their estimates, some general indications of the relation of estimated yields to observed yields may be drawn from the frequency distributions of Exhibit 21.

Given that one of the loading functions is to be used, should it be based on the distance-to-stream adjustment or the percent-area-disturbed adjustment? Visual comparison of the frequency diagrams in Exhibit 21 suggests that the former provides a somewhat better agreement between estimated and observed values, but this difference is sufficiently slight to be viewed as insignificant. The user could base his choice on whether distance-to-stream data or disturbed-area data are more readily available.

Recommendations for Improved Loading Functions - Since the fitted loading functions have been empirically derived from a rather small data set, they should be subject to further testing, preferably in areas of the Midwest and central U. S. from which no data were obtained. In view of the observed impact of season on sediment yield, it appears important to obtain sufficient data to permit treating seasonal effect as a separate variable.

It would be adviseable either to design and carry out a series of experiments for this purpose or to locate similar experiments now under way and to determine which factors necessary to the soil loss equations are missing from those projects. Such data could then be collected in conjunction with the ongoing studies in order to eliminate the need for a large number of estimations.

Some of the data that should be gathered in future studies include:

- Accurate site descriptions including areas and timing of soil exposure, slope length, slope steepness, and amount of internal drainage.
- Position of construction with respect to stream.
- Character of land between stream and site including slope, cover, and potential sediment traps.
- Continuous monitoring of both rainfall and sediment flow.
- Information on other sediment sources in the basin.
- Runoff and sediment data from control basins unaffected by construction.

One construction site that appears particularly well suited to providing needed data is the construction of Interstate I-70 over the Vail Pass in Colorado. This project is being monitored for several environmentally-related parameters by a coordinating group representing several Federal agencies, including the Denver regional office of EPA. With minimal additional effort, excellent data could be obtained for developing an improved loading function for construction activities.

HOW TO USE THE LOADING FUNCTIONS

Since both of the loading functions developed here are modifications of the Universal Soil Loss Equation, their use essentially represents a manipulation of the results obtained by applying this equation to a given area. If the Universal Soil Loss Equation is used to estimate the sediment loss for a given area disturbed by construction operations, the loading functions can be used to modify this estimate to obtain a more accurate estimate of the quantity of soil that will enter a receptor waterbody located a distance from the disturbed area.

Comments on Use of the Universal Soil Loss Equation

The Universal Soil Loss Equation is shown in the preceding subsection titled "History of Sediment-Loss Equations," and the factors that make up the equation are briefly described there. This presentation is not sufficiently detailed to enable a potential user to apply the equation either to an agricultural area or a construction site. The use of this equation is described in detail in referenced publications, including Predicting Rainfall Erosion from Cropland East of the Rocky Mountains, published by the USDA Agricultural Research Service (Reference 6-3), and Comparative Costs of Erosion and Erosion and Sediment Control published by the U. S. Environmental Protection Agency (Reference 6-6). Since the description of procedures for using the Universal Soil Loss Equation are somewhat lengthy, and since the procedures are detailed in other publicly available publications, they will not be repeated here.

To the potential user of the Universal Soil Loss Equation for the purpose of obtaining inputs to the loading functions presented here, we offer the following comments concerning evaluation of certain factors of the equations.

R-Factor (Rainfall) -

If sufficiently detailed precipitation and hydrographic data are available, the "single-storm" method may be used. If not, the "average annual" method may be used. References 6-3 and 6-6 describe slightly different approaches for evaluating R by the single-storm method. The results of these methods are compared in an earlier subsection titled "Comparison of Two Methods for Computing R for Single Storms" (See page 87).

The importance of seasonal effects on predictive capability of loading functions has also been discussed in a previous subsection. When the average annual method is used, it is possible to account (to some degree) for seasonal variations in rainfall by a procedure described in Reference 6-3.

C-Factor (Cropping or Ground Cover) -

In all of the cases used to fit loading functions, the assumption was made that the soil was denuded and possibly subsoils were exposed. Since there was no cover crop, the C-Factor was assigned a value of "1". These same conditions will probably obtain at any construction site, and a value of "1" used for C.

P-Factor (Erosion Control Practice) -

P represents the reduction in soil loss by use of control measures. The procedures described for evaluating P in References 6-3 and 6-6 pertain primarily to agricultural practices. In fitting the loading functions, a value of "1" was assigned to P, corresponding to no control measures. We suggest that the user also assigned this value to P when no control measures, or measures of undetermined efficiency, are used. When measures of known and proven efficiency are used, P may appropriately be assigned the value of its efficiency. (Thus, if the control measure reduced soil loss to 60 percent of the loss if no control were employed, P would have a value of 0.60.)

Estimation of Soil Loss by Use of Loading Functions - A Numerical Example

When an estimate of soil loss from a construction area has been obtained by use of the Universal Soil Loss Equation, it is then adjusted by means of the "delivery-ratio" portion of the loading function. This can be done in either of two ways, depending on what data are available:

- If the distance between the lowest part of the construction site and the receiving stream is known, this distance, expressed in feet, can be used in the equation:

  $$M = Y\ A\ D^{-0.22}$$

  where: M is tons of soil delivered to stream
  Y is soil loss in tons/acre, as estimated by the Universal Soil Loss Equation
  A is size of area disturbed by construction in acres
  D is distance from construction site to stream.
- If the area of the watershed is known and the area disturbed by construction is known, then the ratio of the disturbed area to the total watershed area, expressed as a percentage, may be used in the equation:

  $$M = Y\ A\ (\%A)^{-0.51}$$

  where M, Y, and A are as defined above
  (%A) is percent of watershed area disturbed by construction.

As an example, let us assume that a 20-acre site within a 200-acre watershed is denuded or otherwise disturbed by construction. The Universal Soil Loss Equation predicts a soil loss rate of 25 tons per acre over the estimated period during which the soil is disturbed. If the average distance between the lower boundary of the site (from which drainage will occur) and the receiving stream is 400 feet, then the estimated amount of soil lost to the stream will be:

$$M = (25)\ (20)\ (400)^{-0.22}$$
$$= 134 \text{ tons}$$

Or, if the loading function involving percent area disturbed is used, the calculation would be:

$$M = (25)\ (20)\ (10)^{-0.51}$$
$$= 155 \text{ tons}$$

The authors recommend that the function involving distance-to-stream be used when data are available, since this function gave better fit of estimated to observed soil losses.

REFERENCES

6-1 Musgrave, G. W., "The Quantitative Evaluation of Factors in Water Erosion - A First Approximation," Journal of Soil and Water Conservation, 1947.

6-2 Spraberry, J. A., Predicting Sediment Yields From Complex Watersheds, Paper No. 68-208, U. S. Department of Agriculture, Sedimentation Lab., Oxford, Miss., June 18-21, 1968.

6-3 Wischmeier, W. H., and Smith, D. D., Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains, Soil and Water Conservation, Research Division, Agricultural Research Service, Washington, D.C., May 1965.

6-4 Wischmeier, W. H., "A Rainfall Erosion Index for a Universal Soil Loss Equation," Soil Science Society Proceedings, Vol. 23, 1959, 246-249.

6-5 Wischmeier, W. H., and Smith, D. D., "Rainfall Energy and Its Relationship to Soil Loss," Transactions, American Geophysical Union, Vol. 39, No. 2, April 1958, 285-291.

6-6 Hotes, F. L., Ateshian, K. H., and Sheikh, B., Comparative Costs of Erosion and Sediment Control, U. S. Environmental Protection Agency, Office of Water Program Operating, Water Quality and Non-Point Source of Control Division, EPA-430/9-73-016, Washington, D.C., July 1973.

6-7 Brandt, Gerald H., et al., An Economic Analysis of Erosion and Sediment Control Methods for Watersheds Undergoing Urbanization, W72-08236, The Dow Chemical Co., 191P, February 1972, PB-209-212.

6-8 Wischmeier, W. H., et al., "A Soil Erodibility Nomograph for Farmland and Contruction Sites," Journal of Soil and Water Conservation, Vol. 26, 1971.

6-9 Piest, R. F., and Miller, C. R., "Sediment Sources and Sediment Yields," Chapter IV Proposed ASCE, Manual of Sedimentation Engineering, Journal of Hydraulics Division, Vol. 96, HY 6 June, 1970, 1283-1329.

6-10 Roehl, J. W., "Sediment Source Areas, Delivery Ratios and Influencing Morphological Factors," International Association of Scientific Hydrololgy, Pub. No. 59, 1962.

6-11 Williams, Jimmy R., and Berndt, Harold D., "Sediment Yield Computed With Universal Equation" Journal of Hydraulics Division, Proceedings of the American Society of Civil Engineers, HY 12, Vol. 98, Dec. 1972, 2087-2098.

6-12 Foster, G. R., and Meyer, L. D., "A Closed Form Soil Erosion Equation for Upland Areas", Ch. 12, Sedimentation-Proceedings of Symposium to Honor Prof. H. A. Einstein at Colorado State University, Ft. Collins, Colo. 1972.

6-13 Yorke, T. H., and Davis, W. J., Sediment Yields of Urban Construction Sources, Montgomery County, Maryland, A progress report, Rock Creek-Anacostia River Basins, U. S. Department of Interior, Geological Survey, Parkville, Md., 1972.

6-14 Vice, R. B., et al., Sediment Movement in an Area of Suburban Highway Construction Scott Run Basin, Fairfax County, Virginia, 1961-64: Hydrologic Effects of Urban Growth, U.S. Geological Survey Water - Supply 1591-E, 1973.

6-15 Guy, H. P., "Residential Construction and Sedimentation at Kensington, Md." Reprint from Proceedings of the Federal Inter-Agency Sedimentation Conference, 1963, Misc. Pub. No. 970, Agricultural Research Service, Paper No. 3, June 1965,30-37.

6-16 Guy, Harold P., and Clayton, Terry L., "Technical Notes, Proc. Paper 10024," Journal of the Hydraulics Division, Vol. 99, No. HY 9, September 1973, 1651-1658.

6-17 Reeder, Howard E., Sediment Resulting From Construction of an Interstate Highway in the Piedmont Area of North Carolina, U.S. Geological Survey, North Carolina State Highway Commission, Open-File report, 1973.

6-18 Diseker, E. G., and E. C. Richardson, "Erosion Rates and Control Methods on Highway Cut," Transactions, American Society of Agricultural Engineering, Vol. 5, 1962, 153-155.

6-19 Reed, L. A., Effects of Roadway and Pond Construction on Sediment Yield Near Harrisburg, Pennsylvania, U.S. Geological Survey, Open-File Report, August 1971.

6-20 Knott, J. M., Effects of Urbanization on Sedimentation and Floodflows in Colma Creek Basin, Calif., U. S. Department of Interior, Geological Survey, Water Resources Division, Menlo Park, Calif., February 22, 1973.

6-21 Wischmeier, W. H., and L. D. Meyer, "Soil Erodibility on Construction Areas", Soil Erosion: Causes and Mechanisms; Prevention and Control, Highway Research Board Special Report No. 35, Washington, D. C., 1973.

6-22 Meyer, L. D., W. H. Wischmeier, and W. H. Daniel, "Erosion, Runoff and Vegetation of Denuded Construction Sites", Transactions of the ASAE, Vol. 14, No. 1, 1971.

6-23 Guy, H. P. and D. E. Jones, "Urban Sediment in Perspective", Journal of the Hydraulics Division, ASCE, December 1972.

6-24 Roth, C. B., et al., Prediction of Subsoil Erodibility Using Chemical, Mineralogical, and Physical Parameters, Office of Research and Monitoring, US EPA, Washington, D. C., December 1973.

SECTION VII

METHODS OF CONTROLLING POLLUTION FROM HYDROLOGIC MODIFICATIONS

A variety of methods are available for controlling water pollution from hydrologic modification activities. The diversity is illustrated by the following combinations of methods and applications:

Application	Actual or Proposed Control Method
Suction Dredging	In-line oxidation of dredged material
Operation of dams and impoundments	Selective release and mixing of different layers from a stratified impoundment
Out-of-water construction (residential or commercial development)	Installation of storm drainage system prior to construction of buildings, and use of silt filters around storm drains

Most of the available data on control methods pertain to out-of-stream construction, where the materials to be controlled and the methods of control are fairly well defined. This situation is contrasted to certain dredging activities where it is sometimes difficult to define which parameters should be controlled in order to prevent pollution (or perhaps re-pollution) of the water.

TYPES OF CONTROL MEASURES

Out-of-Stream Control Methods

Most of the available information addresses the control of erosion and sediment. No additional information has been revealed by the present survey on controlling the transport of pesticides or pollutants other than sediment from construction sites, although a model of pesticide transport has been developed for the EPA Southeastern Environmental Research Laboratory and is expected to be tested for various soil types.(7-1)

Out-of-stream control methods fall into two main categories: vegetative controls and structural controls. Vegetative controls are those measures involved in establishing or reestablishing a ground cover at the construction site. This includes the various mulching and tilling operations and combinations thereof. The mulching and tilling processes are considered only as a part of the vegetative control measures because they are not meant to be permanent. Rather, the different applications of organic mulches, rock, chemical mulches (such as polyvinyl alcohol, resin products, elastomeric polymer emulsions, etc.) and sheets of jute netting or plastic, are meant to serve as protection for the topsoil until the vegetation becomes established.

Structural control measures for out-of-stream construction include small flood control dams, dikes, levees, sediment basins and outfall structures, terraces, diversion structures and channels, grassed waterways and outlets, grade stabilizing structures such as chutes, checkdams and drop spillways, serrated side slopes for highway cut sections, filter berms, flexible downdrains, flexible erosion control mats, and temporary basins. During the past two years several publications issued by Federal and local governmental agencies have described and evaluated many of the available methods for controlling silt from out-of-stream construction.(7-2),(7-3),(7-4) These publications present descriptions and constructions detail for many of the structural control methods. References 7-3 and 7-4 present cost data for certain of the control methods. Reference 7-4 also provides cost comparison for specific control measures for different areas of the Nation.

An economic analysis of control methods, unusual in its synthesis of field observations, construction company estimates, and theoretical sediment yield estimates, is the study of control methods as applied to the Seneca Creek watershed in Maryland.(7-5) This study is summarized as Case 42 of Appendix F.

Control Measures for In-Stream Construction Sites, Operation of Impoundments, and Dredging

In the Fryingpan-Arkansas and Teton Dam Construction sites presented in Case 22 of Appendix C, the use of closed water processing systems, settling basins, filters, and flocculants has been successful in controlling water turbidity. A filtering system was used at Cunningham Tunnel. Where there is more space available, larger settling basins may be effectively substituted for filtering systems.

Increased suspended sediment and resulting increased deposition can be controlled, at least in part, by channel control structures in-stream. Increased flow rates caused by stream realignment, etc., also increase bank erosion. This, too, can be controlled by structures.

Revetments such as riprap (dumped, hand-placed or windrowed), cement concrete or asphalt concrete, filter blankets, jetties, vegetation, or chemical stabilization as well as different types of mattresses all protect stream banks from increased erosion potential caused by channel modification. To guard against deposition of sediment in navigable channels, dikes may be constructed which cause deposition along the sides of a river and direct an increased flow toward the channel which is consequently scoured by the greater velocity and kept open for navigation. Channel straightening and subaqueous lining also increases velocity and thus decreases deposition.

Sediments and other pollutants will be deposited in reservoirs to some extent. If the reservoir is large enough, the water it contains will probably be stratified. This offers another opportunity to control the quality of the water downstream. By selective withdrawal of stratified layers of the reservoirs waters, the quality of the water that reaches points downstream can be enhanced.

Few methods exist to control water pollutants released by dredging or other types of bottom disturbances. Perhaps the most effective approach is appropriate planning. Since bottom material is usually deposited in layers, harmful deposits may exist under several layers and cause little or no harm when left undisturbed. Thorough surveys should precede any dredging operation in order to determine whether or not any toxic substance will be released by the activity.

Oxygen level is severely diminished for a certain short time following disposal of dredged material. Research has been done concerning the possibility of oxidation of the dredge material before it is deposited in order to alleviate this condition. Approaches include in-line oxidation during suction dredging and induced-turbulance aeration during sludge hauling. Methods of filtering dredge material before disposal as well as the use of flocculants are being experimented with.(7-6)

The type of control used during dredged material disposal depends on whether or not containment or dispersal is sought. Containment is usually the course of action when the dredged material being deposited is toxic. In this case, it is usually deposited on land within dikes, but some work has been done on the use of chemicals that will allow the material to be disposed of as solid aggregate. Control measures in dispersal depend largely on planning to insure that the receiving water and its benthic environment are compatible with the material to be dispersed.(7-7)

EFFECTIVENESS OF CONTROL MEASURES

Published information on the effectiveness of control measures is scarce and available information incomplete. Most of the available quantitative data is for out-of-stream construction, with practically none for in-water activities.

Out-of-Stream Construction

Most published information is based on results of soil loss measurements from experimental plots rather than actual, large-scale construction operations:

- By application of various combinations of netting, seed, fertilizer, and polymer emulsion to 10 x 44 ft. plots on a roadside fill with 80 percent gradient, Bethamy and Kidd(7-8) obtained soil loss reductions ranging from 70 to 95 percent compared with an untreated plot, over an 11 month period. (See Case Study 35 in Appendix F)

- By application of various combinations of seed, mulch, straw, and asphalt emulsion and by using various tilling and pressing methods on 6 x 30 foot experimental plots of 40 percent gradient on highway slopes in 4 north Georgia counties, Barnett, et al. obtained soil loss reductions ranging from about 50 to 90 percent relative to bare plots. The experiments extended over a 2-year period. (See Case Study 39)

- By applying staw mulch to 10 x 30 foot experimental plots on a 15 percent slope, Meyer, Wischmeier, and Foster obtained soil loss reductions ranging to 33 to 96 percent relative to bare plots. Measurements were made during a simulated rainstorm totaling approximately 5 inches and applied over a period of about 4 hours. (See Case Study 40)

- By application of woodchips and stone chips, gravel, straw, and Portland cement mulches in various combinations to 6 x 35-foot plots with 20 percent gradient at a highway construction site in Indiana, Meyers, Johnson, and Foster observed soil loss reductions ranging from 83 to 5 percent relative to bare soil, following simulated rainfall totaling 5 inches and applied during a two-day period. (See Case Study 41)

In addition to these experimental results obtained from small pl soil loss reductions from various types of control measures are reported in the Fairfax County, Virginia, Erosion Siltation Control Handbook(7-3) and in another EPA publication.(7-4) The reported values, which will not be repeated here in detail, range from 90 percent (for wood cellulose fiber and ryegrass) to 99 percent (for grass sod), all relative to bare soil. The experimental results summarized above, and presumably those given in the Fairfax County handbook, refer to sediment lost from a disturbed area, not to the amount reaching a receptor watercourse.

The question of soil loss from large construction sites and developing areas is addressed by Brant, et al., in an interesting synthesis of field data and theoretical analysis.(7-5) These investigators estimate that for large, developing areas, soil loss reductions of around 60 percent can be achieved by relatively simple and inexpensive measures such as seeding, fertilizing and mulching, if applied well in advance of construction. Reductions of exceeding 95 percent can be achieved by addition of structural measures such as sediment basins. (See Case Study 42)

In-Stream Activities (Dredging, In-Water Construction)

Virtually no quantitative data are available. The reader may be able to draw some rough conclusions by examining the partially reduced turbidity data for dam construction operations presented in Case Study 22.

REFERENCES FOR SECTION VII

7-1. Crawford, N. H., and Donigan, A., Jr., Pesticide Transport and Runoff Model for Agricultural Lands, Hydrocomp, Inc., EPA 660/2-74-13, Prepublication copy (December 1973).

7-2. Becker, B. C., et al., Guideline for Erosion and Sediment Control Planning and Implementations, Hittman Associate, Inc., for Maryland Department of Water Resources and the U. S. EPA, Washington, D.C. 20460.

7-3. Fairfax County (Virginia) Erosion-Siltation Control Handbook, Fairfax, Virginia (December 1973).

7-4. Hotes, F. L., et al., Comparative Costs of Erosion and Sediment Control for Construction Activities, EPA-430-73-016, Engineering-Science, Inc., for U.S. EPA, Office of Water Program Operations, Washington, D.C. (July 1973).

7-5. Brandt, G. H., et al., An Economic Analysis of Erosion and Sediment Control Methods for Watersheds Undergoing Urbanization, W72-08246, The Dow Chemical Co., 191P, PB-209-212 (February 1972).

7-6. U. S. Army Corps of Engineers, "Dredge Materials Research," ODMR, Misc. Paper D-73-3 (July 1973).

7-7. Andreluinas, V. L., "Real or Imaginery Dilemna?," Water Spectrum Vol. 4, No. 1 (1972).

7-8. Bethlahmy, N., and Kidd, W. J., Jr., Controlling Soil Movement from Steep Roadfills, Boise, Idaho, U. S. Forest Service Research Note INT-45, USDA, Inter-Mountain Forest and Range Experiment Station (1966).

SECTION VIII

CASE STUDIES

In the data acquisition phase of this study, some 500 published data sources were reviewed and 104 personal communications made. Relatively few of the publications contained data of value to the study, although many of the personal communications produced useful information. Certain of the publications and unpublished projects revealed by personal communications contained information of such value that it was summarized as "case studies", which outline the project and present essentially all of the reported data considered useful for the present project. These case studies were prepared primarily for use in the present study, but contain an extensive compilation of data that might well be useful in other investigations. For this reason, 42 case studies are presented in Appendices A through F of this report.

GENERIC CONTENT OF CASE STUDIES

In addition to presenting quantitative data, each case study describes the basic study in which the data were developed. In certain of the case studies, the findings are compared with results reported in other studies. The following information is included in the case studies:

- Reference to source of information
- Purpose of study
- Site location and description
    - soil type
    - topography
    - climate
- Study method
- Parameters measured
- Time frame
- Results

All of the cases summarized did not contain information on each of the above topics nor did each one fit easily into this pattern of presentation, but by-and-large the above format is followed for all case studies.

HOW TO ACCESS THE CASE STUDY DATA

Case studies pertaining to each of the major categories of hydrologic modifications are presented in separate appendices. In addition, there is an appendix for case studies or control methods.

Appendix	Category
A	Highway Construction
B	Urban Construction
C	Dams and Impoundments
D	Channelization
E	Dredging and In-Water Construction
F	Control Methods

Types of Data in Each Case Study

Many of the case studies include data on more than one of the above categories. In particular, most of those on highways, urban construction, or dams also contain data on control methods. To aid in indicating more completely the types of information contained in each case study, two cross-indexes were prepared. Exhibit 22 shows which case studies contain information for general topics within each category of hydrologic modifications. Exhibit 23 shows which specific parameters were monitored or measured in each case study.

Several of the case studies report data from controlled experiments. Exhibit 24 lists the parameters controlled in each of these cases.

Exhibit 22. GENERAL TOPICS COVERED IN CASE STUDIES

Topics	Case Study Number
Highway Construction	
Causing Sedimentation on Land	1,2,3,4,6
Affecting Water Body	1,3,4,5,7
Control of Sediment Loss	2,35,36,37,38,39,40,41,42
Areal Construction	
Causing Sedimentation on Land	9,11,12,13
Affecting Water Body	1,9,10,14,15,16,17,18,19,22,23
Control of Sediment Loss	17,12,39,40,41,42
Dam and Reservoir Construction	21,25,26,27
Dredging and Dredged Material Disposal	28,29,30,31,32,33,34
Control Measures	
Economic Considerations	42
Mulches	2,35,26,28,39,40,41,42
Revegetation	2,36,39,41,42
Mechanical-Structural	21,22,33,37,42

Exhibit 13. PARAMETERS MEASURED OR MONITORED IN CASE STUDIES

PARAMETERS / CASE #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Channel/Stream/Lake Morphology																X				X				X	X	X				X												
Characteristics of Receiving Water (Dredge Studies)																												X	X	X	X	X										
Chemical Characteristics of Dredge Spoils																												X	X	X	X	X	X	X								
Chemical Characteristics of Sediment						X						X							X				X														X					X
Effects on Biota					X										X		X						X		X		X			X	X	X										
Land Use	X	X	X	X		X	X	X	X	X	X		X	X	X	X	X	X	X	X				X			X															
Mineralogic Characteristics of Dredge Spoils																												X	X	X	X	X		X								
Mineralogic Characteristics of Sediment						X		X				X																														X
Physical Characteristics of Dredge Spoils																												X	X	X	X	X	X	X								
Physical Characteristics of Sediment	X	X	X	X		X	X	X		X	X	X		X	X								X																			X
Rainfall	X	X	X	X		X	X	X	X	X	X		X	X	X			X				X	X				X								X	X	X	X	X	X	X	X
Revegetation																																				X	X		X		X	
Soil Loss Derived from Universal Soil Loss Equation						X																																				X
Soil Loss Measured	X	X	X	X			X	X	X	X	X	X	X	X	X		X	X																	X	X	X	X	X	X	X	
Soil Characteristics/Geology	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X		X		X	X		X	X	X	X	X								X	X	X	X	X	X	X	X
Topography	X	X	X	X		X	X	X	X	X	X		X	X	X	X	X	X		X		X	X	X	X	X	X								X	X	X	X	X	X	X	X
Turbidity			X															X			X	X																				
Water Discharge							X	X	X		X			X	X																						X			X	X	X

Exhibit 24. PARAMETERS CONTROLLED
IN CASE STUDIES

Topics	Case Study Number
Fertilization	2,36,39,42
Mulch Rate	40,41,42
Mulch Type	2,35,36,38,39,41,42
Rainfall	2,12,38,39
Revegetation	2,36,37,42
Structural Controls	21,22,33,37,42
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Geographic Distribution of Case Study Sites

To aid the potential user in identifying data sources within particular physiographic regions, those case studies located within each major physiographic region of the U.S. are shown in Exhibit 25.

REFERENCES AND EXHIBITS WITHIN THE CASE STUDIES

All references to bibliographic or other sources within the case studies appearing in Appendices A through F are consolidated in a single List of References which appears in Appendix G.

Exhibits within any case study are, in general, reproduced from the referenced source document for that case study. Except where a case study involves more than one referenced source, the source is not, in general, shown on each separate exhibit. All exhibits reproduced photographically utilized the best copy available to the authors. Some of the "originals" were of poor quality, such as xerographic copies of stripchart records. Most data tabulations were retyped when the quality of the original was poor, except when the tabulation was unusually extensive or complex. The authors regret that some of the exhibits in the appendices are not of the best quality, but believe that they serve adequately to convey the information contained in the original.

Exhibit 25. PHYSIOGRAPHIC REGION OF CASE STUDIES (EXCLUDING DREDGING)

Region	Page
Atlantic Plains	
Case Number	
16	291
37	469
Cascade - Sierra Mountains	
Case Number	
15	286
21	325
Interior Plains	
Case Number	
12	244
13	253
23	342
25	365
26	369
38	472
41	490
Intermountain Plateau	
Case Number	
35	462
Nationwide	
Case Number	
27	373
Northern Rocky Mountains	
Case Number	
5	184
Pacific Border	
Case Number	
8	203

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Exhibit 25 (Continued). PHYSIOGRAPHIC REGION OF CASE STUDIES

(EXCLUDING DREDGING)

Region	Page
Piedmont	
Case Number	
1	148
2	156
4	173
9	225
10	234
11	238
14	262
17	294
19	311
20	317
24	351
36	465
39	479
41	490
Southern Rocky Mountains	
Case Number	
22	329
Valley and Ridge	
Case Number	
3	161
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APPENDIX A: EFFECTS OF HIGHWAY CONSTRUCTION ACTIVITIES ON WATER QUALITY

General

This appendix summarizes seven case studies that contain data on the effects of highway construction on water quality. Data from the case studies are included in the summaries. For clarity, each case study begins on a separate page. (See Appendix G for list of references)

Case 1. Sediment Resulting from Construction of a Section of Interstate Highway I-40 in North Carolina

Source -

Reeder, Howard F., Sediment Resulting from Construction of Interstate Highway I-40 in North Carolina, USDI, Geological Survey, Open File Report, Raleigh, N.C., 1973.(A-41)*

Purpose -

The investigation was undertaken to provide information to the North Carolina State Highway Commission concerning means of controlling erosion at and transport from highway construction areas.

Site Location/Description -

The study was made at the headwaters of Hollow Creek at the point where I-40 crosses the Southern Railway in Research Triangle Park in Wake County, near Nelson, N.C. The total area which is drained by Hollow Creek above the settling basin monitored in this study is 24 acres (See Exhibit 26).

Soil Type -

Reddish brown sand-silt loam, about 25% sand, 54% silt, and 20% clay prevails in this small basin. About 1% of the soil material is larger than 2 mm in diameter.

Land Use/Ground Cover -

Highway construction and waste dump covered 83%, or 20 acres, of the area which formerly was entirely a forested area.

Time Frame -

This construction activity began April 1971 with the clearing operations. Rough grading began in May 1971 and the initial survey of

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*Superscripts refer to List of References in Appendix G.

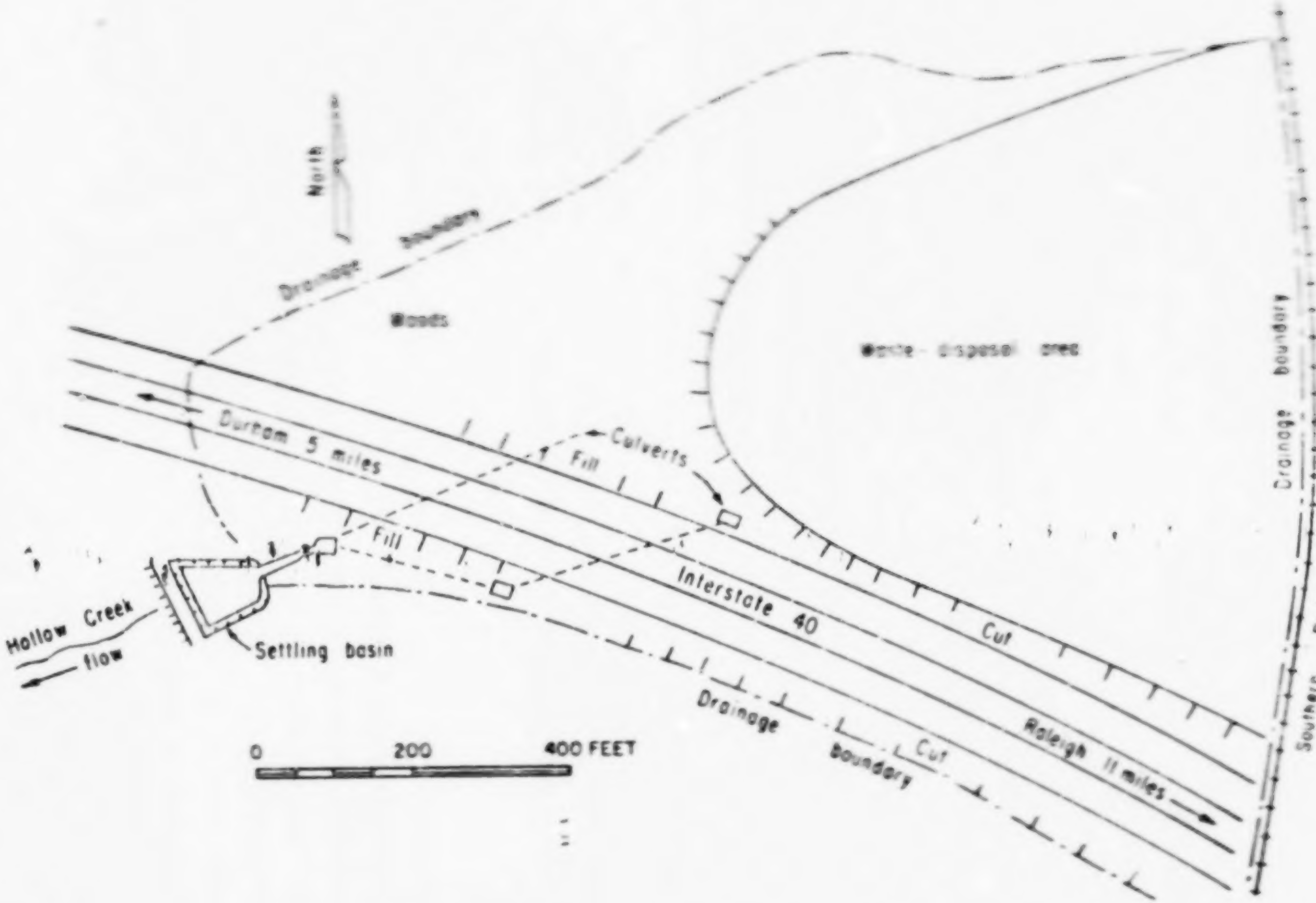

North
Drainage boundary
Woods
Waste disposal area
Durham 5 miles
Culverts
Fill
Fill
Interstate 40
Cut
Raleigh 11 miles
Drainage boundary
Cut
Drainage boundary
Southern Railway
Hollow Creek
flow
Settling basin
0
200
400 FEET

Exhibit 26. Sketch of Project Site on Interstate 40 in the Research Triangle Park Near Nelson, N.C.

sedimentation commenced in July.

Study Method -

In order to observe the effects that storm events had on sedimentation and erosion at certain phases of road construction, the volume of sediment deposited in a settling basin was measured over time. This settling basin was formed by an earthen dam 85 feet long which had an initial capacity of some 720 cubic yards with depths varying from 3.5 to 5 feet. Culverts, one from the waste dump area and one from the highway cut area, drained into the basin.

Parameters Measured-

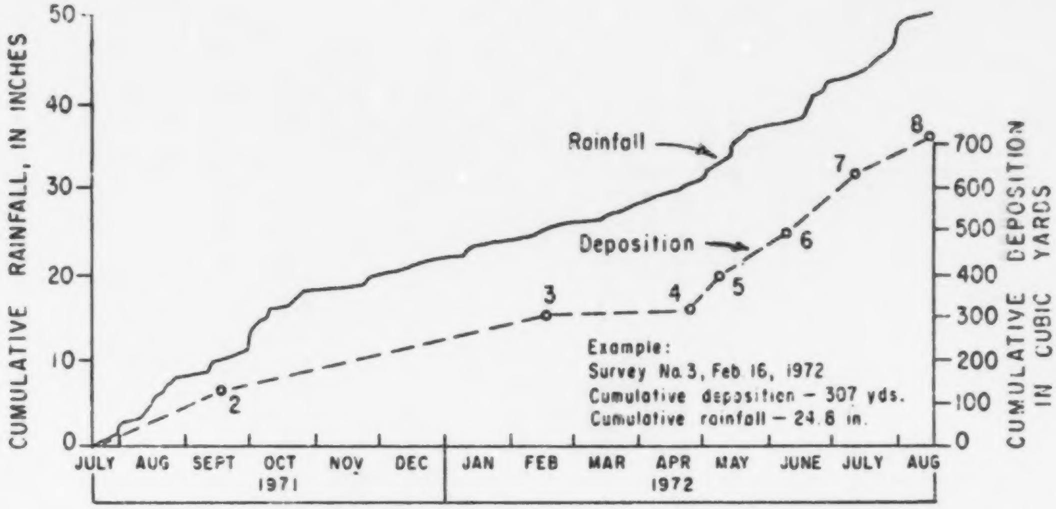
Several parameters which were measured through conventional methods and through the use of the settling basin are of interest for developing loading functions: daily rainfall (continuous measurement); water level (continuous); total runoff; sediment deposition; sediment concentration at culverts, a dam spilling, and overflow pipes (from samples taken during certain rainfall events); and sediment particle size (from samples). These measurements offered adequate information to derive an analysis of trap efficiency and other selected parameters.

Results -

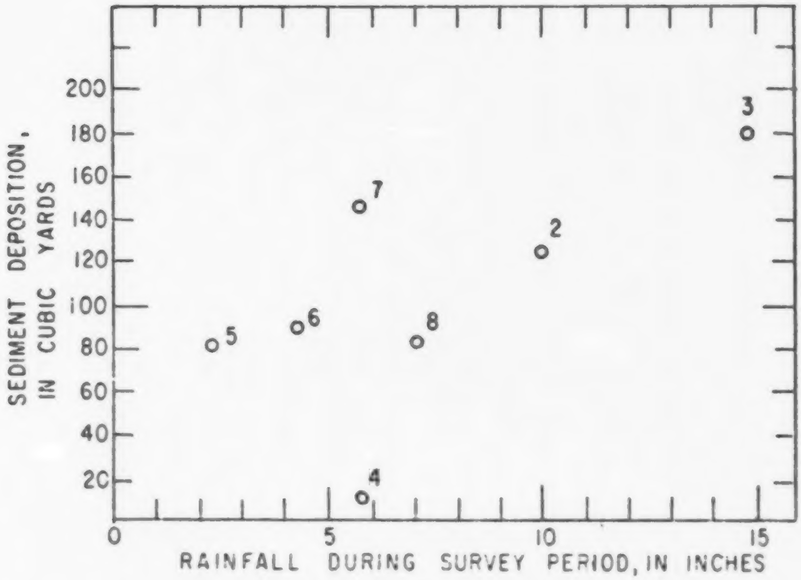
The referenced study contains summary presentations of data for all of the parameters listed above. Of particular interest for the present study are the relationships between quantities of sediment deposited, precipitation, and condition of the construction site. These are summarized in Exhibit 27. Rainfall and sediment deposition relationships are shown in Exhibits 28 and 29. Performance of the sediment basin as a sediment trap is shown in Exhibit 30.

Exhibit 27. SEDIMENT DEPOSITED AND PRECIPITATION, I-40

Survey Number	Date	Sed. deposited since previous survey (cu yd)	Precipitation since previous survey (in)	Sed. deposited per inch of precip. (cu yd/in)	Conditions in project area at time of survey
1	July 13, 1971		initial survey		Clearing of project area started Apr. 23, 1971.
2	Sept.16, 1971	126.5	10.01	12.6	Timber and vegetation stripped from about 80 percent of area. Construction and grading have disturbed surface over most of the area.
3	Feb. 16, 1972	180.9	14.80	12.2	Entire construction area rough graded. Most of roadbed at final grade.
4	Apr. 24, 1972	10.6	5.85	1.81	Period of rough and smooth grading. Cuts and roadbed nearing completion.
5	May 8, 1972	80.1	2.31	34.7	Smooth grading almost completed. No grass on other soil cover. Gravel, roadbed in place.
6	June 9, 1972	91.8	4.28	21.4	Smooth grading completed. Area partially grassed mulched on June 9. About half of pavement in place.
7	July 11, 1972	147.6	5.78	25.5	Grass and mulch over most of area. Grass growing but not yet effective against erosion.
8	Aug. 15, 1972	84.7	7.09	11.9	Grass cover completely covering construction area. Pavement and road shoulders complete.
Total		722.2	50.12		



(a) Cumulative rainfall and sediment deposition.



(b) Relation of rainfall to sediment deposition.

Exhibit 28. Rainfall - Sediment Deposition Relationships

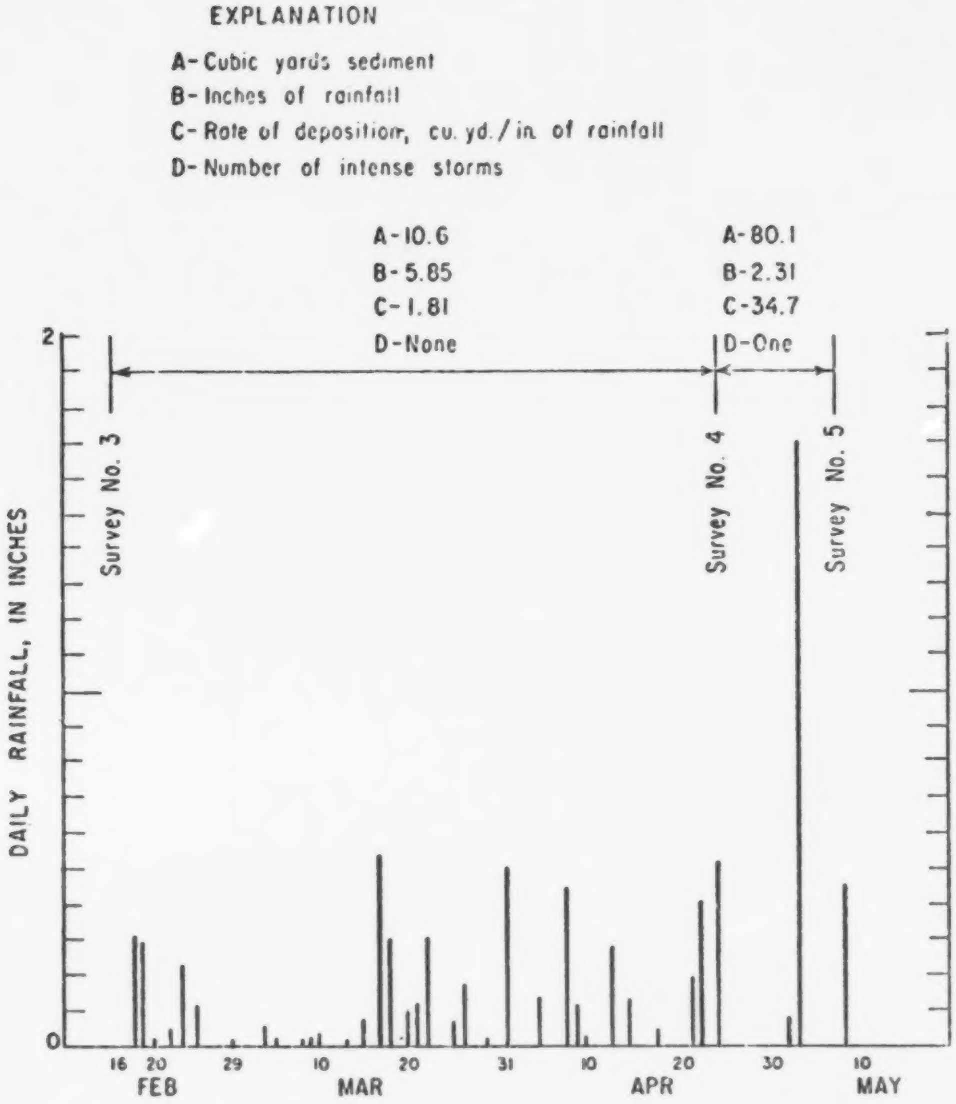


Exhibit 20. Comparison of Sediment Deposition
and Rainfall During Two Consecutive Survey Periods in 1972.

Exhibit 30. SEDIMENT AND TRAP CHARACTERISTICS

Inclusive Survey Nos.	Period	Sediment deposited (cu yd)	Specific weight[a] (lbs/ft³)	Sediment deposited (tons)	Median diameter (mm)	Trap.eff. at end of period (percent)	Avg. trap eff.during period (percent)	Avg. Amt. of sediment lost (percent)	Sediment lost (tons)	Total sediment (tons)	Total sediment (cu yd)	Sediment lost (cu yd)
Init.survey "0"	Prior to Jul.12,1971	0	56	0	0.021	88						
0 - 2	Jul.12,1971 to Feb.16,1972	307	65	270	0.037	76	82	18	59	329	435	128
2 - 5	Feb.16 to June 9	182	66	162	0.047	64	70	30	69	231	306	124
5 - 7	June 9 to Aug. 15	232	69	216	0.082	42	53	47	192	408	540	308
Totals		721		648					320	968	1281	56b

[a] Provided by Soil Testing Laboratory of State Highway Commission.

Also of interest are the concentration of sediments in particular locations in the study area during the storm event of July 31, 1972 (See Exhibit 30). At the storm's peak, sediment concentration was about 7,050 mg/l at the inflow from the waste area; 1,170 mg/l at the culvert that drained the construction area where grass covers had been established; and 2,920 mg/l at the spillway and 2,520 mg/l at the outflow pipe of the dams.

Additional information on trap efficiency, the size characteristics of the sediment, and the relation to size of sediment particles to location of deposition (distance from dam) are given in the report, but the information will not be reproduced here since it is not needed for the development of loading functions.

Case 2. Cartersville, Georgia, Highway Cuts and Erosion

Source -

Diseker, E. G., and Richardson, E. C., "Erosion Rates and Control Methods on Highway Cuts," Transactions, American Society of Agricultural Engineering, Vol. 5, 1962, 153-155.(A-14)

Purpose -

The study was designed to determine the various factors that affect the rates of runoff, erosion, and sediment production from highway cuts and to find the most effective types of plant cover which might be established quickly in order to alleviate the erosion problem.

Site Location/Description -

Six plots were selected within the Coosa River watershed near Cartersville in Barton County, Georgia and were to remain unvegetated for three years. Exhibit 31 summarizes the characteristics of the individual plots used.

Soil Type -

All plots were comprised of Cecil clay soil which was exposed to the B and C horizons.

Time Frame -

Study was begun in the fall of 1956.

Study Method -

In order to make the needed measurements, a runoff sampler was installed at the lower end of each plot ditch. These ditches had masonry head and side walls while concrete aprons and sheet metal covers were constructed for each of the samplers. Of the runoff collected by the sampler, 0.5 percent was diverted to a storage tank

Exhibit 31. CHARACTERISTICS OF ROAD-BANK PLOTS NEAR CARTERSVILLE, GA.

Plot No.	Bank slope, 1 on	Range of bank height, ft	Bank length, ft.	Runoff area, acres	Erodible area acres	Aspect
I	1.4	5-16	206	0.16	0.11	N70°W
II	1.2	5-14	225	.27	.21	S70°E
III	2.5	2-10	365	.21	.14	N70°W
IV	3.3	2-12	310	.30	.20	S70°E
V	1.0	4-15	296	.18	.12	N70°W
VI	1.1	5-15	321	.23	.15	S70°E

located below the flume where the samples were removed for analysis. Scour and deposition were determined by installing rows of metal stakes or pins in each plot. In a separate study to determine the effectiveness of various types of vegetation in controlling erosion, more than 30 plant species and varieties were planted in 800 experimental plots in the same project area on the road banks. Species that were included are the cool season annual and perennial grasses, legumes, and vines as well as warm season species.

Parameters Measured -

Parameters that were dealt with which relate to this study include: Bank of slope; range of bank; bank length; runoff area; erodible area; aspect; soil loss through the flume; soil loss deposited in channel; and total soil loss (soil loss data in tons/acre).

Results -

The following tables present data compiled in this study. Exhibit 32 gives average annual runoff and erosion from bare roadside cuts and flow channels near Cartersville, Georgia. The data were compiled through the use of runoff samplers which were installed in each of the plot ditches. The ditches also had masonry head and side walls so that channel deposition could be recorded. The sampler collected only 0.5 percent of the total runoff from each plot.

Effects of various mulch treatments on establishing crownvetch cover for erosion control are summarized in Exhibit 33. Additional results of the study of the effectiveness of vegetative covers in controlling erosion is given in Case Study 39.

Exhibit 32. AVERAGE ANNUAL RUNOFF AND EROSION FROM BARE ROADSIDE CUTS AND FLOW CHANNELS NEAR CARTERSVILLE, GA.

(January 1, 1958, to December 31, 1960)

Plot	Slope 1 on	Aspect	Average Annual				
			Rainfall, in.	Runoff, in.	Soil loss, tons per acre		
					Through flume[a]	Channel deposition[b]	Total area erosion[c]
I(medium)	1.4	N70°W	45.28	3.86	23.8	265.5	289.2
II(medium)	1.2	S70°E	45.28	5.46	26.5	94.1	120.6
III(flat)	2.5	N70°W	40.10	8.54	127.2	Erosion[d]	129.2
IV(flat	3.3	S70°E	40.10	3.80	42.8	Erosion[d]	42.8
V(steep)	1.0	N70°W	40.10	4.12	41.2	232.6	196.3
VI(steep)	1.1	S70°E	40.10	3.20	23.9	114.3	110.1

Slightly less than half of the 68 rains produced runoff.

[a] Soil losses from the bare bank and channel calculated from water stage recorder data.

[b] Soil losses from the bare bank deposited in the channel calculated from the lower three rows of metal hub stakes.

[c] Total area erosion loss is the sum of loss through flume and channel deposition.

[d] Erosion from the channel indicated by hub stake calculations was accounted for by the measuring device.

[e] These are 2-year averages. The first year these steep slopes were firm because they had just been resloped. This condition made them resistant to infiltration and frost action during 1958.

Exhibit 33. EFFECT OF MULCHES ON DENSITY OF CROWNVETCH COVER NEAR CARTERSVILLE, GA.[a]

Mulch and date of planting		Percent of Crownvetch cover[b]			
		Bank sections			
		Upper	Middle	Lower	Average
Planting of September 17, 1959					
No mulch (average)		41	17	9	22
Jute		31	19	18	23
Jute		47	24	21	31
Pine straw		74	50	45	56
Wheat straw 2 T/A		78	75	73	75
Wheat straw 4 T/A		90	90	87	89
White plastic		35	18	17	23
Sawdust		51	46	32	43
Average	No mulch	41	17	9	22
	Mulch	58	46	42	49
Planting of March 21, 1960					
No mulch (average)		15	13	22	17
Pine straw		52	78	72	67
Wheat straw 2 T/A		55	80	86	74
Wheat straw 4 T/A		62	79	69	70
Sawdust		42	60	53	52
White plastic		29	29	58	39
Jute		22	41	55	39
Water-soluble latex		25	23	34	27
Average	No mulch	15	13	22	17
	Mulch	41	56	61	53

[a] Site 36: Cecil soil, 20-30-ft bank, west exposure, 1-on-2 slope.

[b] Cover ratings were made on the same date by four individuals and the average of the four ratings is shown.

Case 3. Construction at the Site of Interstate Highway I-81, Near Harrisburg, Pa.

Sources -

(a) Reed, L. A., "Effects of Roadway and Pond Construction of Sediment Yield Near Harrisburg, Pennsylvania," Open File Report, U.S. Geological Survey, Harrisburg, Pennsylvania, August 1971.(A-39)

(b) Reed, L. A., et al., Progress Reports No. 17 (Jan. 1, 1973 to March 31, 1973), and No. 21 (Jan. 1, 1974 - March 31, 1974), on Research Project No. 68-34, "Evaluation of Erosion Control Measures Used in Highway Construction," U. S. Geological Survey, Water Resources Division, Harrisburg, Pa.(A-40)

(c) "Evaluation of Erosion Control Measures Used in Highway Construction," Undated project summary, received by MITRE in June, 1974, from U.S. Geological Survey, Harrisburg, Pa.(A-53)

Purpose -

To determine the effectiveness of sediment control measures during highway construction on stream sedimentation, the Pennsylvania Department of Transportation and the U. S. Geological Survey initiated a study of five adjacent stream basins.

Site Location/Description -

The basins were located just west of Harrisburg, Pa. (See Exhibit 34) Four of the basins are crossed by Highway I-81, and the fifth basin serves as a control.

Topography -

The configuration of the land ranges from relatively steep to nearly flat. Mountain slopes average 30 percent with some as high as 50

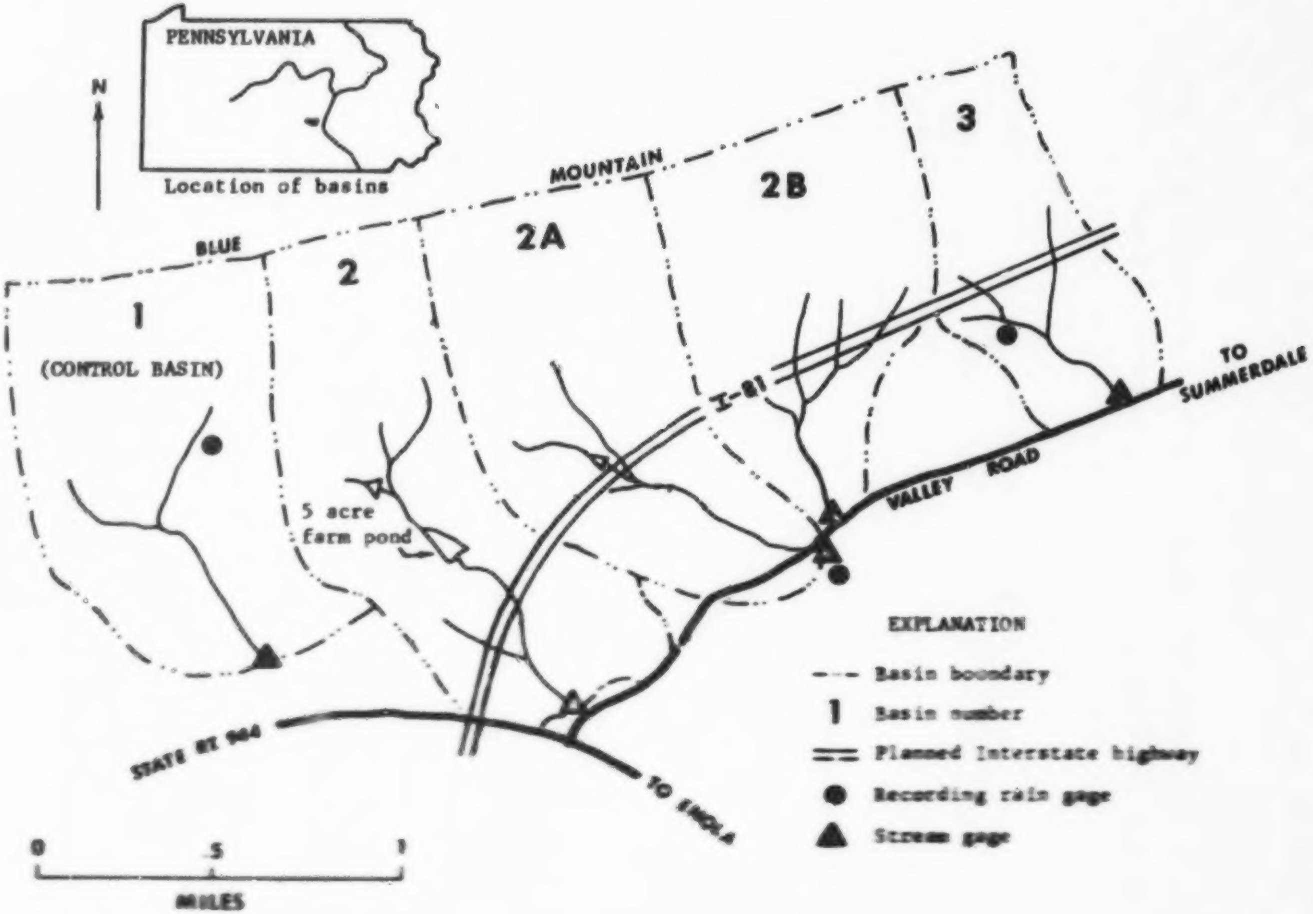

PENNSYLVANIA
Location of basins
N
BLUE
MOUNTAIN
1
(CONTROL BASIN)
2
2A
2B
3
5 acre farm pond
I-81
VALLEY ROAD
TO SUMMERDALE
STATE RT 944
TO ENOLA
EXPLANATION
Basin boundary
Basin number
Planned Interstate highway
Recording rain gage
Stream gage
0
.5
1
MILES

Exhibit 3A. Location of Basins and Data-Collection Sites, I-81

percent, while valley slopes between bases of mountains and gaging stations average about 4 percent.

Soil Types -

The soil types in the five basins range from stony to stony-and-gravelly loams. Some valley soils are shaley silt loams.

Land Use/Ground Cover. -

Mountainous areas and the steeper slopes of valleys are forested, while flatter areas of the valleys are open fields and are partially used as farmland. The rest of the area is grassland.

Special Note -

Two separate investigations were undertaken at the site described above. Both involved the measurement of sediment yield, and the measurement of meteorological, hydraulic, and land use parameters. The first case (3a) is a project currently in progress involving the construction of I-81. The second case (3b) is an earlier project on the same site involving a description of the effects of two smaller construction projects in one of the basins prior to the construction of I-81. These two smaller projects are a one-lane road and a five-acre pond. Case 3b has been completed and a report has been issued covering that material (A-40). Case 3a is currently in progress and, as a result, complete data were not available at the time of this writing.

Case 3a. Evaluation of Erosion Control Measures Used in Highway Construction

The following is extracted from the above source reference (c) listed at the beginning of Case 3.

Study Method -

"Streamflow and precipitation parameters are being monitored from five adjacent basins located just west of Harrisburg. Four of the basins are being crossed by I-81 construction and the fifth, which is not being disturbed, is serving as a control."

"The roadway in the four basins will be subject to different types of erosion and sediment control, most of which have been incorporated into the construction contract and roadway design. In general, drainage in one of the four basins (2A) will be kept separate. The existing streams will be piped through the construction area and drainage or runoff from the construction area will be detained in off-stream ponds designed to hold 1-inch of runoff. Existing regulations regarding seeding and mulching, diversions, maximum velocities, rock dams, dikes, and berms will also be enforced."

"The roadway in basin (2B) will also be constructed according to existing regulations. In addition, a large farm pond-type desilting structure is being provided downstream of the construction. The additional sediment caused by the construction of the pond is being measured."

"The existing sediment control regulations will be the only controls enforced in Basin 3. Sediment control prior to 1968 will be practiced in Basin 2, and a desilting structure will be placed below the stream gage in Basin 2 to trap excess sediments."

"The data will be analyzed to show the decrease in suspended sediment realized through enforcement of the existing regulations by comparing Basin 2 to Basin 3; to show the effectiveness of large on-stream structures by comparing Basin 2 and 3 with 2B; and to show the effectiveness of keeping the drainage separate and treating the runoff from the construction before allowing it to enter the stream by comparing Basins 2 and 3 with 2A."

Parameters Measured -
"Stream data being collected from the five basins include three items: stream flow, sediment concentration, turbidity levels. The data are collected as frequently as 15-minute intervals to enable us to compute and tabulate maximum and mean water discharge, maximum and mean suspended-sediment concentration, maximum, mean, and water weighted turbidities, and the weight of suspended-sediment discharge, all on a daily basis."

Time Frame -
"Construction of the roadway, I-81 was started in November 1972; to date, the clearing operation has been completed. Drainage and embankment work are still in early stages."

"To date, we have about 3 years of preconstruction data and 6 months of construction data analyzed (through May 30, 1973). A report has been written regarding the construction of a farm pond by a local property owner.* A report on 2 years of the preconstruction data has been prepared but is not yet approved for release. A short paper on the clearing operation is now in preparation."

Results -
Little data for this project have been released as of this writing; however, some reports containing measurement data are expected to be

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*See Case 3(b).

issued within a short time (October or November 1974).

Preliminary observations indicate that the amounts of sediment discharged, as the cut and fill work in the interstate approaches final grade, range from 5 to 10 times the yield normally expected (i.e., in the absence of construction). The watersheds exhibiting the lower rate of increase contain one or more sediment ponds.

Preliminary observations also show an increase in the proportion of clay contained in the soil materials being transported--from 40 percent before construction to 70 percent during construction. Top soil in the area averages 16 percent clay; subsoils, 25 percent. Preliminary data indicate that the amount of sand being transported has not been changed but that the quantities of silt and clay have increased some 4-fold and 15-fold, respectively.

Case 3b. Effects of Roadway and Pond Construction

Source -

See Source Reference (c) listed at the beginning of Case Study 3.

Study Method

Data were collected from Basin 2 (Conodoguinet Creek tributary) before and after the construction of a one-lane roadway and a farm pond within the basin as part of the pre-construction data collection program for the I-81 study. The normal storage capacity of the completed 5-acre area and construction of the pond disturbed a 10.5-acre area. The drainage area above the pond is 302 acres. All streamflow was retained by the pond (after completion) until November, 1971, when the pond overflowed.

Continuous water discharge data were collected at the gaging sites on Conodoguinet Creek Tributary 1 (control) and Conodoguinet Creek

Tributary 2 (construction) in order that the data from each may be compared to determine the effects of the roadway and pond construction. Suspended sediment concentration data were collected periodically during base-flow periods and every 15 minutes during storm events at a point downstream of the construction sites. Turbidity was also measured downstream of the construction with a surface-scatter turbidimeter.

Parameters Measured -

- Water runoff
- Suspended sediment concentration
- Turbidity

Time Frame -

The road was constructued during June and July 1970, and the pond was constructed during August and September of the same year.

Results -

Monthly water discharge from Basin 1 (control basin, no construction) and Basin 2 (where pond and a one-lane roadway were built) prior to construction is shown in Exhibit 35.

EXHIBIT 35

MONTHLY WATER DISCHARGE, IN CFS-DAYS, 1969-70

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Total
Basin 1	2.5	7.8	23	16	78	35	96	32	12	19	4.2	330
Basin 2	3.2	14	31	19	81	37	100	25	13	26	4.4	350

Suspended sediment concentration for Tributaries 1 and 2 (corresponding to Basins 1 and 2) is shown in Exhibit 36, together with average water discharge for base-flow periods. It is noted that during June and July the roadway construction reached within 300 ft. of Tributary 2 channel, but that a large storm was required (see early July) to transport much of the sediment to the stream channel. The suspended sediment concentration in the runoff from both basins was approximately the same prior to construction but changed markedly during construction. This is shown by Exhibit 37 which presents a plot of suspended sediment concentration (cumulative) for Tributary 2 versus the same parameter for Tributary 1.

Similarly the basins discharged roughly equal quantities of sediment prior to construction; for example, Tributary 1 discharged 62 tons while Tributary 2 discharged 58 tons. The quantities discharged from each basin during and prior to the construction period are shown in Exhibit 38, which is a plot of the cumulative amounts of sediment discharged by the two basins.

Turbidity of the streams also was affected by construction activities, particularly the pond construction. Quantitative effects are shown in Exhibit 39, with both turbidity and water discharge measurements.

In summary, the base-flow sediment concentration increased from an expected 6 mg/l to an average of 35 mg/l during pond construction. After the pond had been overflowing for one month, the sediment concentration below the dam averaged about twice the expected value. Sediment discharge attributable to construction of the road and pond was about 55 tons, which is some 66 percent of the yearly amount expected from the basin in the absence of construction.

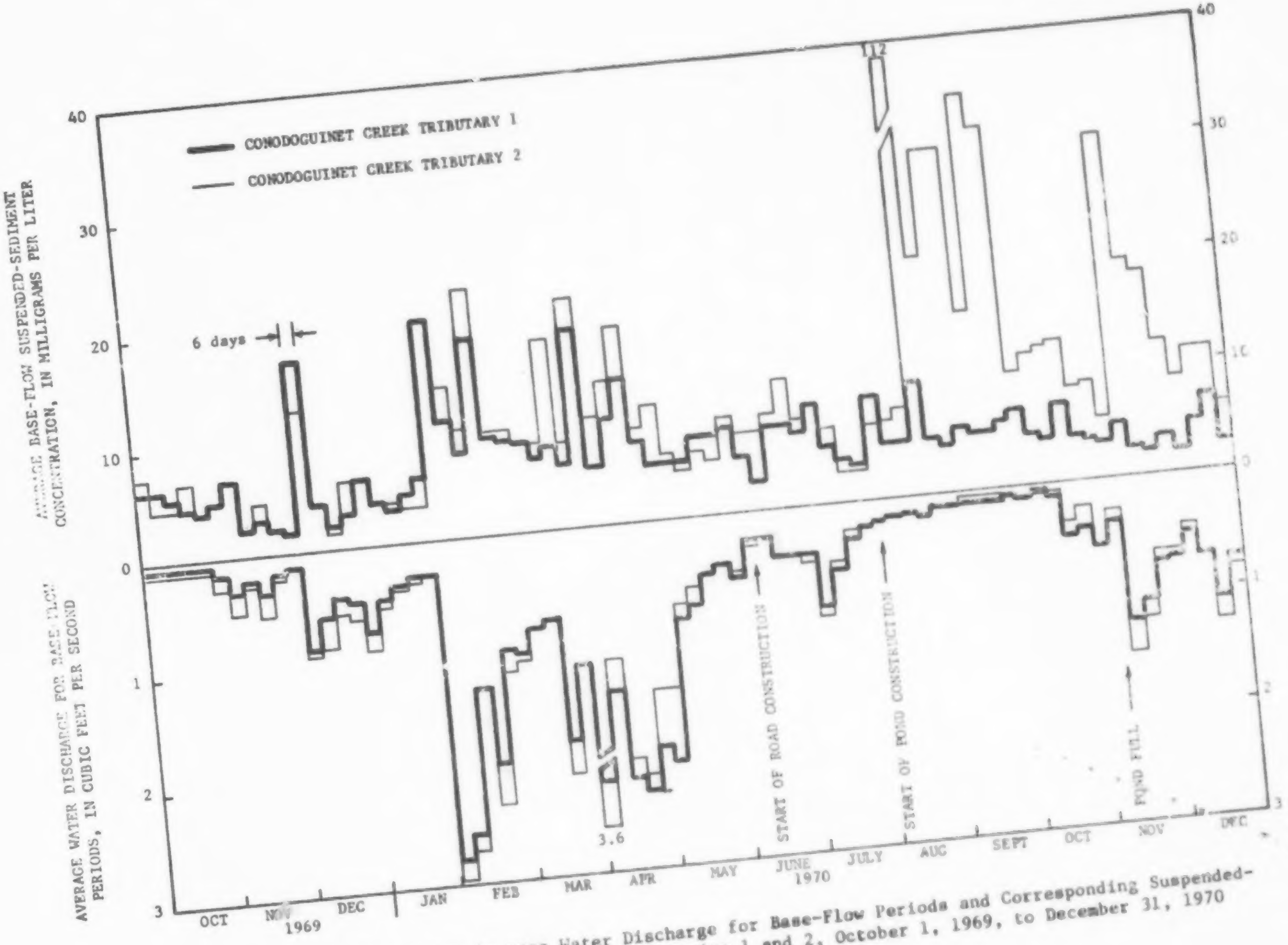

Exhibit 36. Hydrograph Showing Average Water Discharge for Base-Flow Periods and Corresponding Suspended-Sediment Concentrations, Conodoguinet Creek Tributaries 1 and 2, October 1, 1969, to December 31, 1970

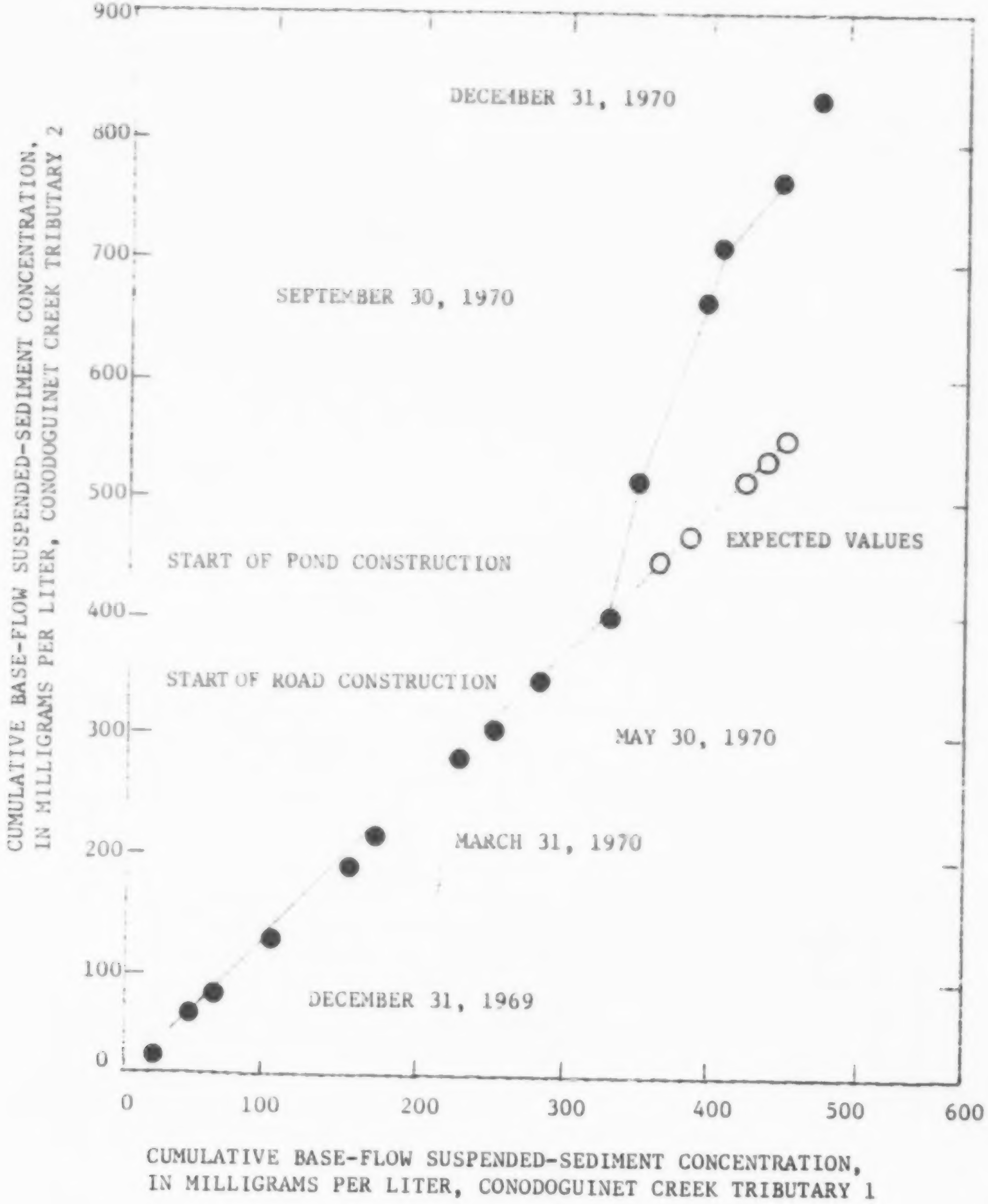

Exhibit 37. Double-Mass Relation of Average Base-Flow Suspended-Sediment Concentrations by 6-Day Periods, Conodoguinet Creek Tributaries 1 and 2. October 1, 1969, to December 31, 1970

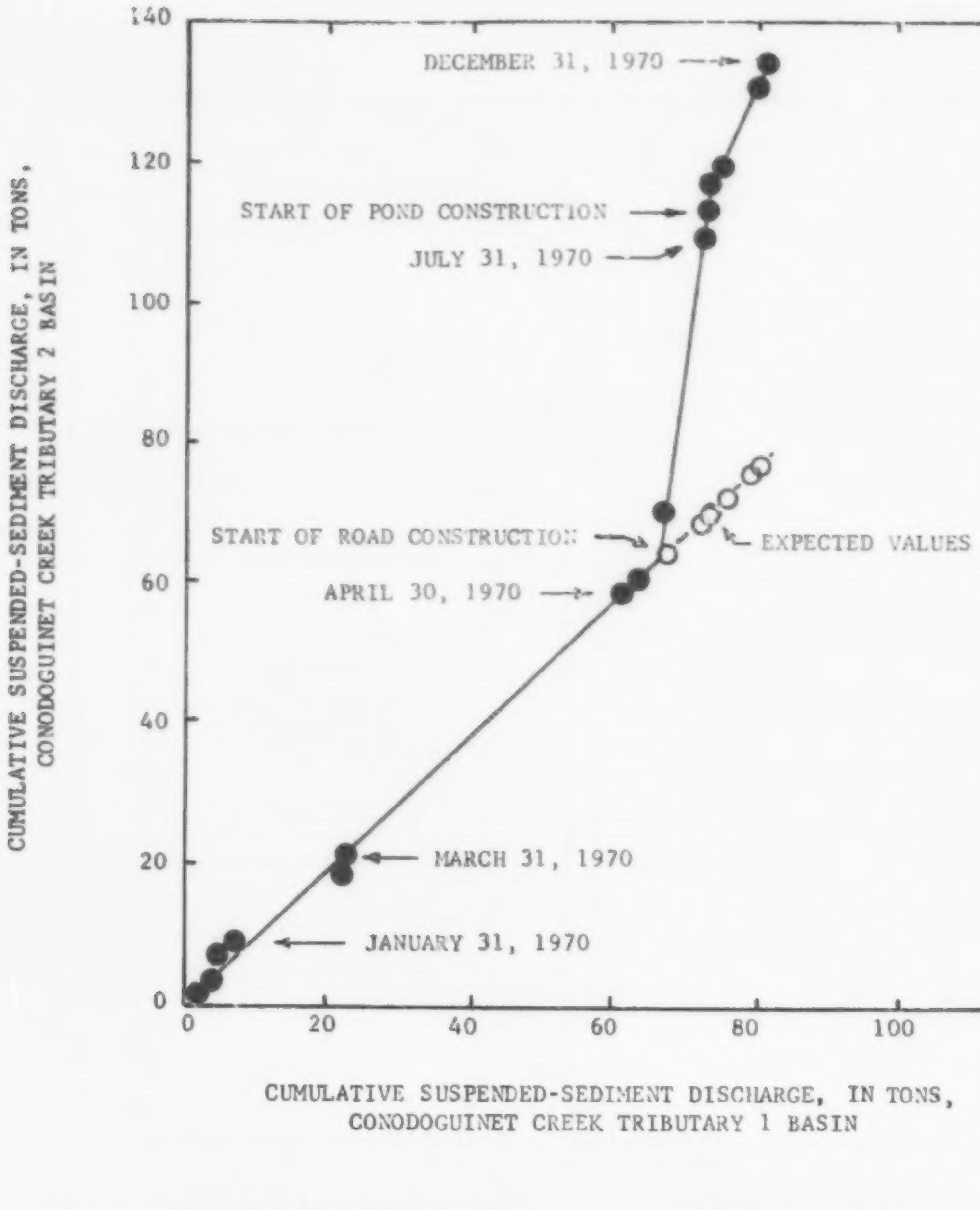

Exhibit 38. Double-Mass Relation of Sediment Discharge, Conodoguinet Creek Tributaries 1 and 2, October 1, 1969, to December 31, 1970

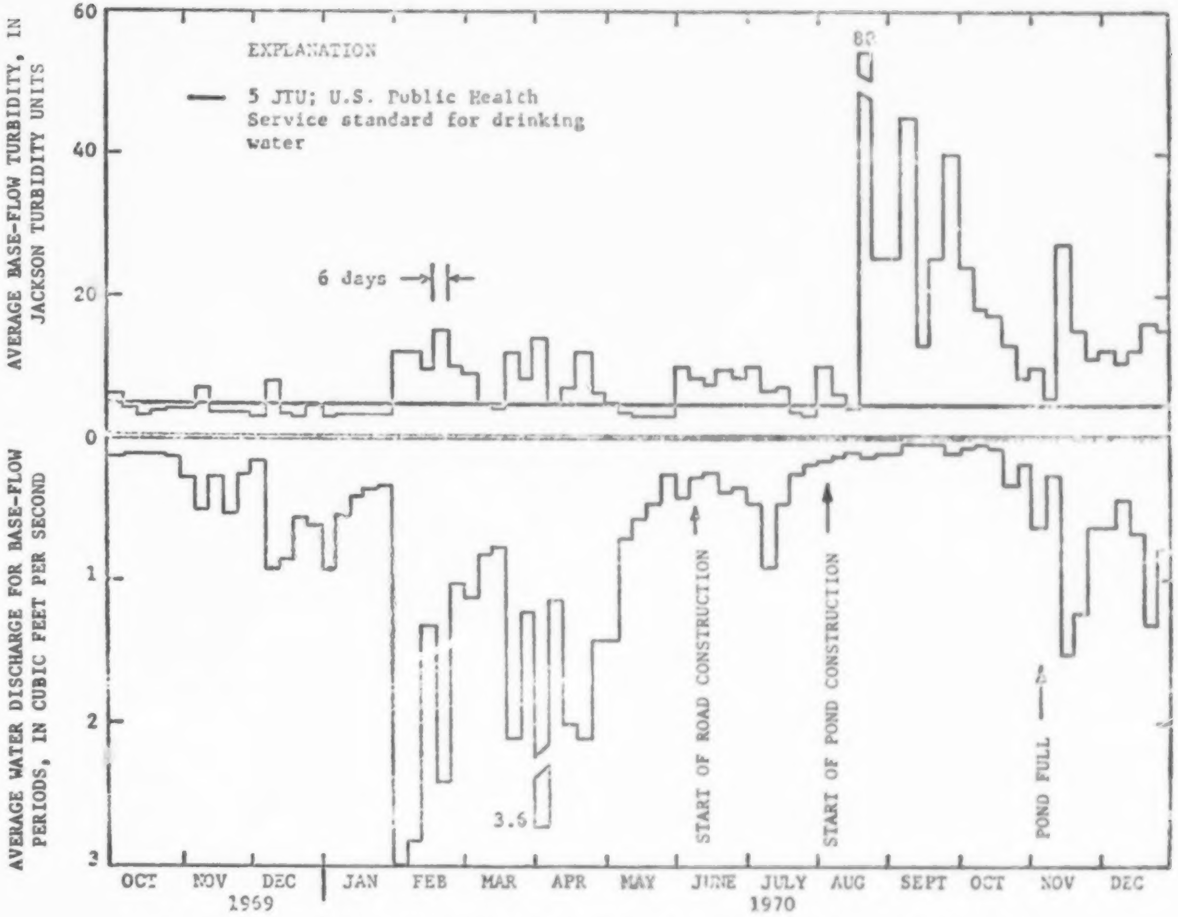

Exhibit 39. Average Base-Flow Turbidities and Corresponding Water Discharges, Conodoguinet Creek Tributary 2, October 1, 1969 to December 31, 1970

Case 4. Highway Construction in Scott Run Basin, Virginia

Source -

Vice, R. B., Guy, H. P., Ferguson, G. E., Sediment Movement in an Area of Suburban Highway Construction, Scott Run Basin, Fairfax County, Virginia, 1961-1964, Hydrologic Effects of Urban Growth, U. S. Geological Survey, 1591-E, U.S. GPO, Washington, D. C., 1969.(A-54)

Purpose -

A study was undertaken in the Scott Run basin from 1961 to 1965 in order to determine the extent to which soil disturbed by highway construction and associated activities might be eroded and carried away by runoff.

Site Location/Description -

The Scott Run basin lies in Fairfax County, Virginia, and it extends from the mouth of Scott Run at the Potomac River (60 feet above sea level) southward about 4.5 miles to the basin's source at Tysons Corner (about 330 feet above sea level). The total drainage area is about 4.54 square miles.

Topography -

The slopes of the stream channel vary from 0.10 to 0.04, and the average slope of the ground is approximately 0.02.

Soil Type -

The soil in this area is mostly friable and is derived from deep weathering of schist in the Wissahickon formation. Some of the southern stretch is comprised of a remnant of the Bryn Mawr gravel which overlies the Wissahickon formation.

Climate/Rainfall -

The climate is fairly moderate with January and February averages ranging from 20 to 50F. The July average is in the upper 80's F.

The average frost-free season is April 10 through October 28. Rainfall during the time of the study averaged 40.4 inches per year. Runoff is presented in Exhibit 40.

Land Use/Ground Cover -

Land use in the Scott Run Basin is varied (See Exhibit 41.)

Study Method -

Samples of sediment concentration during 29 storms were taken for analysis. For 59 unmeasured storms, the sediment discharge in tons was computed by the equation

sediment discharge = YTAE

where Y = mean storm event sediment-transport rate in tons/day/acre of construction corresponding to the measured mean of 29 storms.
T = duration of storm runoff in days
A = area of construction in acres
E = mean seasonal erodibility factor

Parameters Measured -

- Water discharge (duration, mean rate, volume)
- Sediment yield (per day, accumulated)
- Construction area
- Size composition of suspended sediment transported

Results -

The Scott Run Study is a well known case in erosion and sedimentation monitoring from highway construction. The data concerning water discharge sediment yield and related variables by storm events are presented in Exhibit 42. This data allowed for the computation of sediment discharge of 59 unmeasured storms through the derivation of Y (mean storm event sediment-transport rate in tons/day/acre of con-

Exhibit 40. DISTRIBUTION OF STORM-RUNOFF EVENTS BY RATE OF RUNOFF AND SEASON, SCOTT RUN BASIN, 1961-64(A-54)

Quarter	Average rate of storm runoff (cubic feet per second)					Total
	10-20	21-40	41-80	81-140	141-200	
January - March	7	11	11	1	- - - -	30
April - June	6	15	5	2	1	29
July - September	4	4	3	1	1	13
October - December	2	8	4	2	- - - -	16
Total	19	38	23	6	2	88

Exhibit 41. LAND USE IN SCOTT RUN BASIN, 1961 - 64(A-54)

Time	Low-yield area					Intermediate-yield area		High-yield area			
	Forest (acres)	Grass (acres)	Established urban (acres)	Total		Cultivated and quarry		Highway construction		Other construction	
				(acres)	(percent)	(acres)	(percent)	(acres)	(percent)	(acres)	(percent)
1961											
April	1,320	920	290	2,530	87.0	130	4.4	250	8.6		
July	1,280	820	290	2,390	82.2	210	7.2	310	10.6		
October	1,270	910	290	2,470	84.9	140	4.8	300	10.3		
1962											
January	1,270	970	290	2,530	87.0	70	2.4	310	10.6		
April	1,270	935	290	2,495	85.8	110	3.7	300	10.3	5	0.2
July	1,270	915	290	2,475	85.1	150	5.1	270	9.3	15	.5
October	1,270	995	290	2,555	87.9	110	3.8	230	7.8	15	.5
1963											
January	1,270	1,140	290	2,700	92.8	50	1.7	140	4.8	20	.7
April	1,270	1,170	290	2,730	93.9	70	2.4	85	2.9	25	.8
July	1,270	1,175	290	2,735	94.0	70	2.4	70	2.4	35	1.2
October	1,270	1,190	310	2,770	95.2	70	2.4	35	1.2	35	1.2
1964											
January	1,270	1,230	310	2,810	96.6	40	1.4	35	1.2	25	.8
April	1,260	1,230	330	2,820	96.9	50	1.7	10	.3	30	1.0
July	1,260	1,205	340	2,805	96.5	50	1.7	10	.3	45	1.5
Average	1,272	1,057	299	2,630		94		168		18	

struction corresponding to the measured mean of the 29 measured storms) in the equation:

sediment discharge = YTAE (Factors as defined above)

Exhibit 43 presents the relation between runoff and sediment discharge for storm events which was used to derive Y. Exhibit 44 shows changes in sediment concentration with time.

Exhibits 45 and 46 show the eroded sediment size distribution by year for highway construction areas.

Exhibit 42. SUMMARY OF WATER DISCHARGE, SEDIMENT YIELD, AND RELATED VARIABLES BY STORM EVENTS FOR SCOTT RUN NEAR MCLEAN, VA.(A-54)

Date	Storm measurement No.	Storm runoff			Construction area (acres)	Seasonal adjustment factor	Sediment-transport			Accumulated	
							Rate (tons per day per acre of construction)		Amount (tons)	Water	Sediment
		Duration (days)	Mean rate (cfs)	Volume (cfs-days)			1	2		(cfs-days)	(tons)
1961											
5-12	1	0.58	57.8	33.6	250	0.82	8.4	6.9	995	33.6	995
6-8		.17	28.2	4.8		1.23	2.9	3.6	150	38.4	1,145
6-9		.21	34.8	7.3		1.22	3.9	4.8	250	45.7	1,395
6-10	2	.21	195	41.0		1.23	52.0	64.6	3,390	86.7	4,785
6-25		.125	19.2	2.4		1.16	1.6	1.9	59	89.1	4,844
Total		1.30		89.1					4,844		
7-13		.29	105	30.6	310	1.07	21.0	22.4	2,040	119.7	6,884
8-26	3	.31	183	56.7		.65	47.5	30.7	2,950	176.4	9,834
9-4		.31	53.8	16.7		.84	7.6	6.4	610	193.1	10,444
Total		.91		101.0					5,600		
10-21	4	.42	64.8	27.2	300	.96	10.0	9.6	1,210	220.3	11,654
11-23		.50	25.0	12.5		.60	2.3	1.4	210	232.8	11,864
12-12	5	.42	40.0	16.8		.67	4.8	3.2	402	249.6	12,266
12-17		.29	16.2	4.7		.60	1.2	.7	61	254.3	12,327
12-18		.65	35.4	23.0		.60	4.0	2.4	470	277.3	12,797
Total		2.28		84.2					2,353		

Exhibit 42 (Continued). SUMMARY OF WATER DISCHARGE, SEDIMENT YIELD, AND RELATED VARIABLES BY STORM EVENTS FOR SCOTT RUN NEAR MCLEAN, VA.(A-54)

Date	Storm measurement No.	Storm runoff			Construction area (acres)	Seasonal adjustment factor	Sediment-transport			Accumulated	
		Duration (days)	Mean rate (cfs)	Volume (cfs-days)			Rate (tons per day per acre of construction)		Amount (tons)	Water (cfs-days)	Sediment (tons)
							1	2			
1963											
8-19		0.29	18.3	5.3	105	0.90	1.5	1.4	43	1,085.0	33,082
8-20	19	.25	64.0	16.0		1.08	9.8	10.6	279	1,101.0	33,361
9-20		.38	46.9	17.8		.72	6.1	4.4	180	1,118.8	33,541
Total		.92		39.1					502		
11-1		.42	13.8	5.8	70	.63	1.0	.6	18	1,124.6	33,559
11-6	20	.96	89.6	86.0		.70	16.1	11.2	751	1,210.6	34,310
11-23		.29	32.2	9.0		.60	3.5	2.1	43	1,219.6	34,353
11-29	21	.25	78.8	19.7		.28	13.2	3.7	65	1,239.3	34,418
11-29		.79	71.1	56.2		.60	11.3	6.8	380	1,295.5	34,798
12-8		.38	29.2	11.1		.60	3.0	1.8	48	1,306.6	34,846
Total		3.09		187.8					1,305		
1964											
1-1		.71	31.0	22.0	60	.60	3.2	1.9	81	1,328.6	34,927
1-3	22	.50	55.8	27.9		.84	8.0	6.7	202	1,356.5	35,129
1-7		1.00	20.9	20.9		.60	1.8	1.1	66	1,377.4	35,195
1-9		.92	63.7	63.7		.60	11.0	6.6	360	1,441.1	35,555
1-20		.92	35.6	35.6		.60	4.6	2.8	150	1,476.7	35,705
1-21		.50	11.8	11.8		.60	2.1	1.3	39	1,488.5	35,744
1-25		.88	27.5	24.2	60	.60	2.7	1.6	85	1,512.7	35,829
2-6	23	.75	47.2	35.4		.56	6.1	3.4	154	1,548.1	35,983
2-14		.38	15.5	5.9		.61	1.2	.7	16	1,554.0	35,999
2-22		.58	28.8	16.7		.64	2.9	1.9	66	1,570.7	36,065
Total		7.14		264.1					1,219		
4-2		.62	24.2	15.0	40	.80	2.2	1.8	45	1,585.7	36,110
4-7		.67	22.1	14.8		1.02	2.0	2.0	54	1,600.5	36,164
4-8		.83	36.3	30.1		1.04	4.2	4.4	150	1,630.6	36,314
4-19	24	.40	25.5	10.1		1.21	2.4	2.9	47	1,640.7	36,361
4-20		.31	29.1	9.0		1.38	3.0	4.1	51	1,649.7	36,412
4-30	25	.77	44.0	33.9		1.54	5.6	8.6	265	1,683.6	36,677
5-13	26	.38	39.7	15.1		1.96	4.8	9.4	143	1,698.7	36,820
5-17		.17	21.2	3.6		1.32	1.9	2.5	17	1,702.3	36,837
6-20		.17	20.6	3.5		1.17	1.8	2.1	14	1,705.8	36,851
Total		4.32		135.1					786		
7-8		.125	16.8	2.1	55	1.09	1.3	1.4	10	1,707.9	36,861
8-3	27	.17	22.4	3.8		1.10	2.0	2.2	20	1,711.7	36,881
8-30	28	.17	30.0	5.1		.90	3.1	2.8	26	1,716.8	36,907
9-19		.25	20.4	5.1		.76	1.8	1.4	19	1,721.9	36,926
9-29		.21	29.5	6.2		.72	3.0	2.2	25	1,728.1	36,951
9-30	29	.23	28.4	6.5		.66	2.9	1.9	24	1,734.6	36,975
Total		1.16		28.8					124		
Grand total		39.1		1,734.6					36,975		

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1. Transport rate from regression curve of figure 7 in tons per day per acre of construction.

2. Transport rate as measured or adjusted for seasonal effect in tons per day per acre of construction.

Exhibit 42 (Continued). SUMMARY OF WATER DISCHARGE, SEDIMENT YIELD, AND RELATED VARIABLES BY STORM EVENTS FOR SCOTT RUN NEAR MCLEAN, VA.(A-54)

Date	Storm measurement No.	Storm runoff			Construction area (acres)	Seasonal adjustment factor	Sediment-transport			Accumulated	
		Duration (days)	Mean rate (cfs)	Volume (cfs-days)			Rate (tons per day per acre of construction)		Amount (tons)	Water (cfs-days)	Sediment (tons)
							1	2			
1959											
1-6		0.90	27.6	24.8	310	0.60	2.7	1.6	450	302.1	13,247
1-15		.21	58.6	12.3		.60	8.7	5.2	340	314.4	13,587
2-19		.29	45.9	13.3		.60	5.9	3.4	310	327.7	13,897
2-19		.15	18.6	2.8		.60	1.5	.9	42	330.5	13,939
2-26	6	.48	60.7	29.1		.64	9.0	5.8	865	359.6	14,804
2-27		.52	27.3	14.2		.60	2.7	1.6	200	373.8	15,064
3-12	7	.79	56.1	44.4		.44	8.0	3.5	858	418.2	15,922
3-21		.56	26.3	14.7		.64	2.6	1.7	300	432.9	16,222
Total		3.90		155.6					3,425		
4-1		.71	26.2	18.6	305	.72	2.6	1.9	410	451.5	16,632
4-12		.44	18.4	8.1		1.21	1.5	1.8	240	459.6	16,872
4-13		.19	17.8	3.4		1.23	1.4	1.7	98	463.0	16,970
5-1		.42	122	51.1		1.39	26.0	36.1	4,630	514.1	21,600
5-24		.35	13.4	4.7		1.30	.9	1.2	130	518.8	21,730
5-24		.19	18.4	3.5		1.30	1.5	2.0	120	522.3	21,850
5-26		.35	79.0	27.6		1.29	13.2	17.0	1,810	549.9	23,660
5-31	8	.19	21.1	4.0		2.28	1.8	4.1	236	553.9	23,896
6-19		.125	15.2	1.9		1.18	1.1	1.3	50	555.8	23,946
6-20	9	.52	30.0	15.6		1.10	3.1	3.4	536	571.4	24,482
Total		3.49		138.5					8,260		
9-27	10	.23	13.5	3.1	285	.67	.9	.6	39	574.5	24,521
Total		.23		3.1					39		
11-2		.33	23.3	7.7	245	.62	2.1	1.3	100	582.2	24,621
11-10	11	.54	126	68.1		.58	23.0	13.3	1,770	650.3	26,391
11-18		.31	24.5	7.6		.60	2.3	1.4	110	657.9	26,501
11-21	12	.79	47.7	37.7		.32	6.2	2.0	390	695.6	26,891
12-6		.58	26.9	15.6		.60	2.6	1.8	260	711.2	27,151
Total		2.55		136.7					2,630		
1960											
1-11		.33	25.1	8.3	160	.60	2.4	1.4	74	719.5	27,225
1-12		.71	33.8	24.0		.60	3.7	2.2	250	743.5	27,475
1-13		.42	26.0	10.9		.60	2.5	1.5	100	754.4	27,575
1-19		.25	14.4	3.6		.60	1.0	.6	24	758.0	27,599
2-5		.21	19.5	4.1		.60	1.6	1.0	34	762.1	27,633
2-6		.17	16.5	2.8		.60	1.3	.8	22	764.9	27,655
2-22		.42	52.2	21.9		.60	7.3	4.4	300	786.8	27,955
3-6		.29	89.0	25.8		.97	10.0	9.6	450	812.6	28,405
3-6	13	.46	50.0	22.9		.60	6.6	6.4	459	835.5	28,874
3-12	14	1.00	78.9	78.9	160	.60	13.3	8.0	1,310	912.2	30,184
3-16		.79	19.8	15.6		.62	1.7	1.1	140	930.0	30,294
3-19	15	.83	42.2	35.3		.40	5.3	2.1	283	965.3	30,577
Total		5.88		254.1					3,426		
4-30		.21	27.6	5.8	110	1.40	2.7	3.8	88	971.1	30,665
6-3	16	.79	62.9	49.8		.84	9.3	7.8	683	1,020.9	31,348
6-7		.25	40.4	10.1		1.23	4.9	6.0	160	1,031.0	31,508
6-20	17	.21	50.5	10.6		1.09	6.8	7.4	171	1,041.6	31,679
6-30	18	.38	101	38.1		1.70	19.1	32.5	1,360	1,079.7	33,039
Total		1.84		114.4					2,462		

Page 3 of 3

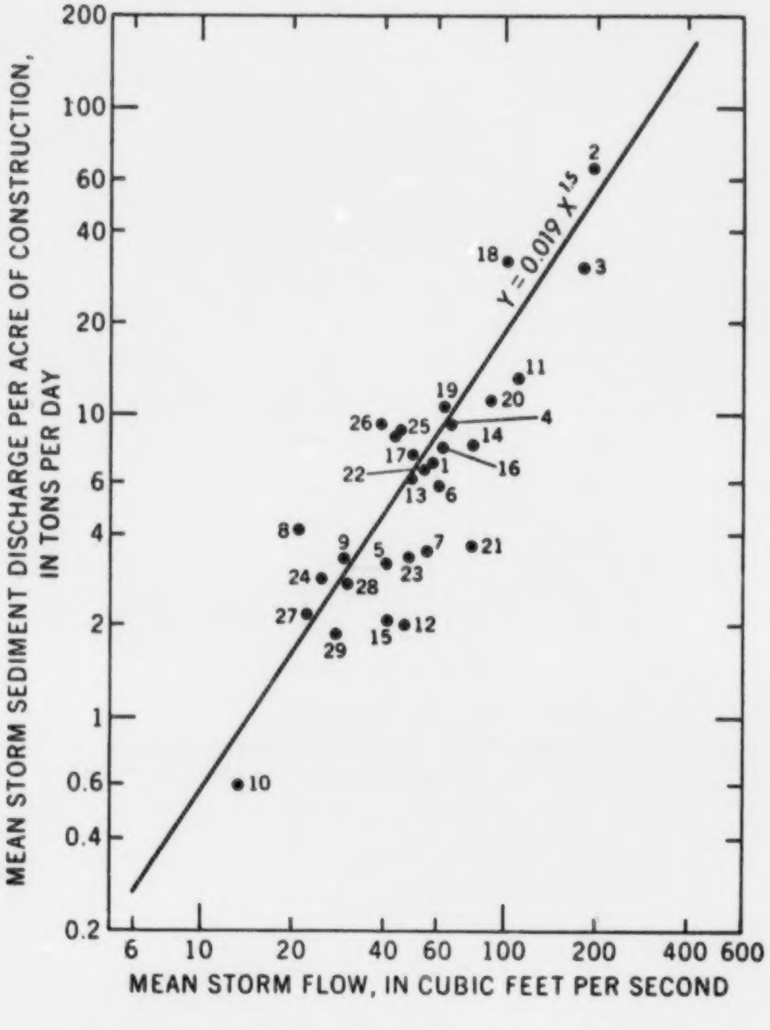

Exhibit 43. Relation Between Runoff and Sediment
Discharge for Storm Events in Scott Run Basin(A-54)

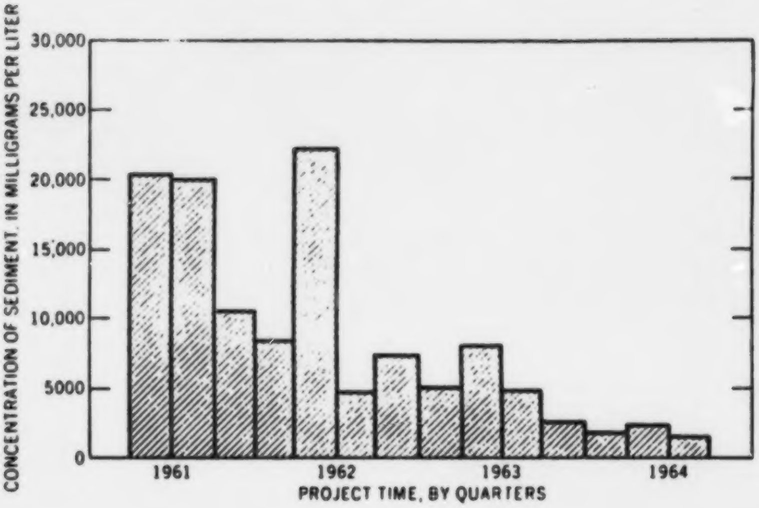

Exhibit 44. Variations in Mean Concentrations of Sediment for Storm Runoff, 1961 - 64(A-54)

Exhibit 45. SIZE COMPOSITION OF SUSPENDED SEDIMENT TRANSPORTED BY STORM RUNOFF FROM SCOTT RUN BASIN, 1961 - 64.(A-54)

Year and quarter	Mean flow of storm runoff (cfs)	Sediment discharge (tons) [1]	Size composition (percent)			Period discharge (tons)		
			Sand	Silt	Clay	Sand	Silt	Clay
1961								
2 [2]	69	4, 844	12	62	26	580	3, 000	1, 260
3	116	5, 600	16	60	24	900	3, 360	1, 340
4	37	2, 353	7	65	28	165	1, 530	660
1962								
1	40	3, 425	8	64	28	275	2, 190	960
2	40	8, 260	8	64	28	660	5, 280	2, 320
3	16	39	1	63	36	0	25	15
4		2, 630	10	63	27	260	1, 660	710
1963								
1	43	3, 426	9	64	27	310	2, 190	920
2	64	2, 462	12	62	26	290	1, 530	640
3	43	502	9	64	27	45	320	135
4	61	1, 305	11	62	27	145	810	350
1964								
1	37	1, 219	7	65	28	85	790	340
2	31	786	6	66	28	45	520	220
3	24	124	4	66	30	5	80	35
Total		36, 975				3, 765	23, 285	9, 905
Percent		100				10	63	27

[1] Computed suspended-sediment discharge from table 3.
[2] Data available only for part of quarter.

Exhibit 46. SIZE COMPOSITION OF SEDIMENT TRANSPORTED BY SCOTT RUN, 1961 - 64(A-54)

	Flow (cfs-days)	Size composition (percent)			Sediment loads (tons)			
		Sand and gravel	Silt	Clay	Sand	Silt	Clay	Total
Suspended sediment loads for storm runoff	1, 735	10	63	27	3, 765	23, 285	9, 905	36, 975
Additional sediment loads for storm runoff [1]		85	15		1, 570	280		1, 850
Estimated sediment loads for intervals between storm events	2, 952		25	75		80	235	315
Total	4, 680	14	60	26	5, 335	23, 645	10, 140	39, 140

[1] Estimated part of total sediment loads during storm runoff that moved below the sampling zone and was not included in computed suspended loads.

Case 5. Effects of Highway Construction on a Montana Stream

Source -

"Shorter Papers and Notes: Detrimental Effects of Highway Construction on a Montana Stream," Transactions of the American Fisheries Society, Vol. 88, 1959, 72-73.(A-47)

Purpose -

This study concerns the effects of highway construction on water quality as indicated by changes in a fish population.

Site Location/Description -

The study took place at Flint Creek which is a tributary of the Clark Fork of the Columbia River, located near Granite County.

Physical Characteristics of the Stream -

The stream has an average width of 20 feet, an average depth of 6 inches, and an average flow of 15 c.f.s.

Biota -

Fish life consisted mainly of rainbow trout (*Salmo gairdnerii*), mountain whitefish (*Prosopium williamsoni*), cutthroat trout (*Salmo clarki*), and brook trout (*Salvelinus fontinalis*).

Study Method -

Fish counts were made before the beginning of a highway construction project that drained into the stream, and after completion of the project. In order to capture fish for tagging in the census-taking process, a 230 volt d.c. portable generator was used for electric shock; the sections of stream to be shocked were blocked off with 1/2-inch mesh seines placed about 30 feet apart.

Time Frame -

The study took place from the fall of 1956 until the summer of 1957.

Results -

This study, conducted to identify any effects which may have overcome the fish population of a small mountain stream because of contingent highway construction, indicated that an overall reduction in both numbers and weight of large size game fish occurred at a rate of 94 percent. Small sized game fish (under six inches total length) had a reduced population by 85 percent and an overall weight loss of 76 percent. Exhibit 47 shows the details of the samples collected.

Exhibit 47. GAME FISH CAPTURED BY ELECTRIC SHOCKER
FROM 300 FOOT SECTION OF FLINT CREEK, MONTANA, 1955 and 1957(A-47)

Species	1955		1957	
	Number	Lbs.	Number	Lbs.
	Large-sized fish			
Rainbow and cutthroat trout	68	12.63	6	1.19
Eastern brook trout	7	3.86	0	0.00
Mountain whitefish	16	2.25	0	0.00
Total large sized fish	91	18.74	6	1.19
	Small-sized fish			
Rainbow and cutthroat trout	46	1.32	6	0.26
Eastern brook trout	6	0.17	2	0.10
Mountain whitefish	1	0.04	0	0.00
Total small-sized fish	53	1.53	8	0.36
Total fish, all sizes	144	20.27	14	1.55

Case 6. Sediment Runoff Control at Highway Construction Sites (I-80) in Pennsylvania

Source -

Swerdon, P. M. and Kountz, S. R., Sediment Runoff Control at Highway Construction Sites, Engineering Research Bulletin B108. The Pennsylvania State University College of Engineering, University Park, January 1973.(A-48)

Purpose -

The purpose of the study was to demonstrate the necessity of having some control measure provided during highway construction in order to safeguard the municipal water supply from deterioration. The site under investigation was known to have produced sediment runoff during actual highway construction which resulted in increased costs of 1 to 3 million dollars for water treatment.

In this study, actual measurements of parameters--rainfall and climatic conditions, topography, etc.--were used to compute pollutant loads by means of mathematical models.

Site Location/Description -

Selected for this study was a 7,000 foot section of I-80 in Union County, Pa. Exhibit 48 shows the layout of highway I-80 and the whole watershed of White Deer Creek; Exhibit 49 shows the Lick Run drainage basin and related construction areas under study.

Topography -

The east side of the construction, which comprises 37 percent or 5.8 acres of the total area exposed, has a flow path of 2200 feet. The average slope of this 15.7-acre drainage area is 4 percent. The west side of the construction takes up the remaining 46 percent of the exposed area (7.1 acres). The largest flow path in this 15.4-acre drainage area is 31,000 feet.

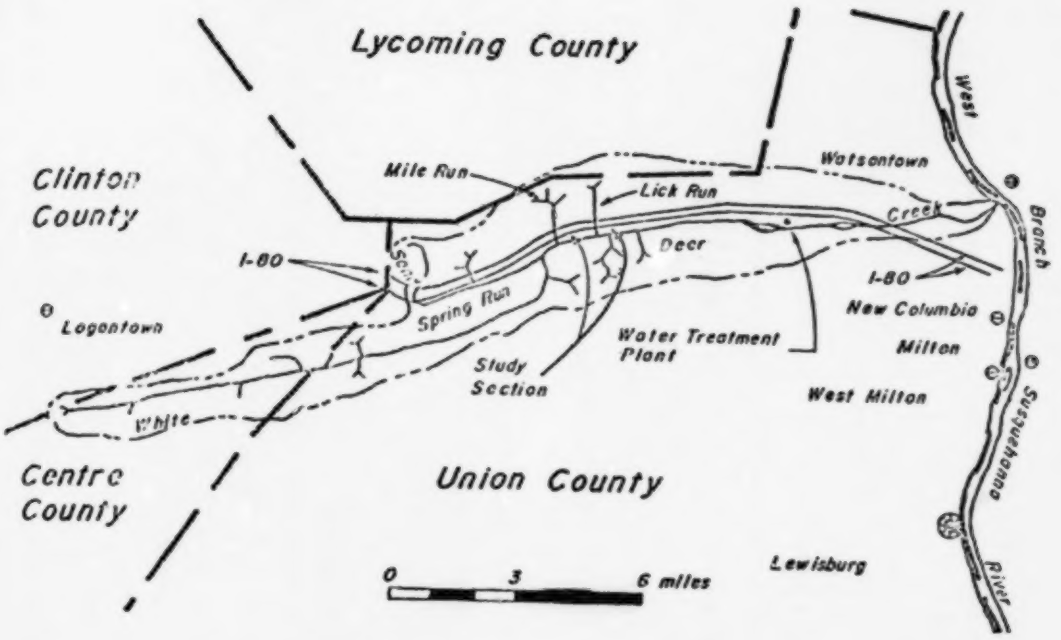
Lycoming County
Clinton County
Centre County
Union County
Logantown
Mile Run
Lick Run
Watsontown
West Branch Susquehanna River
Creek
Deer
White
Spring Run
I-80
I-80
New Columbia
Milton
West Milton
Lewisburg
Water Treatment Plant
Study Section
0
3
6 miles

Exhibit 48. White Deer Creek Watershed$^{(A-48)}$

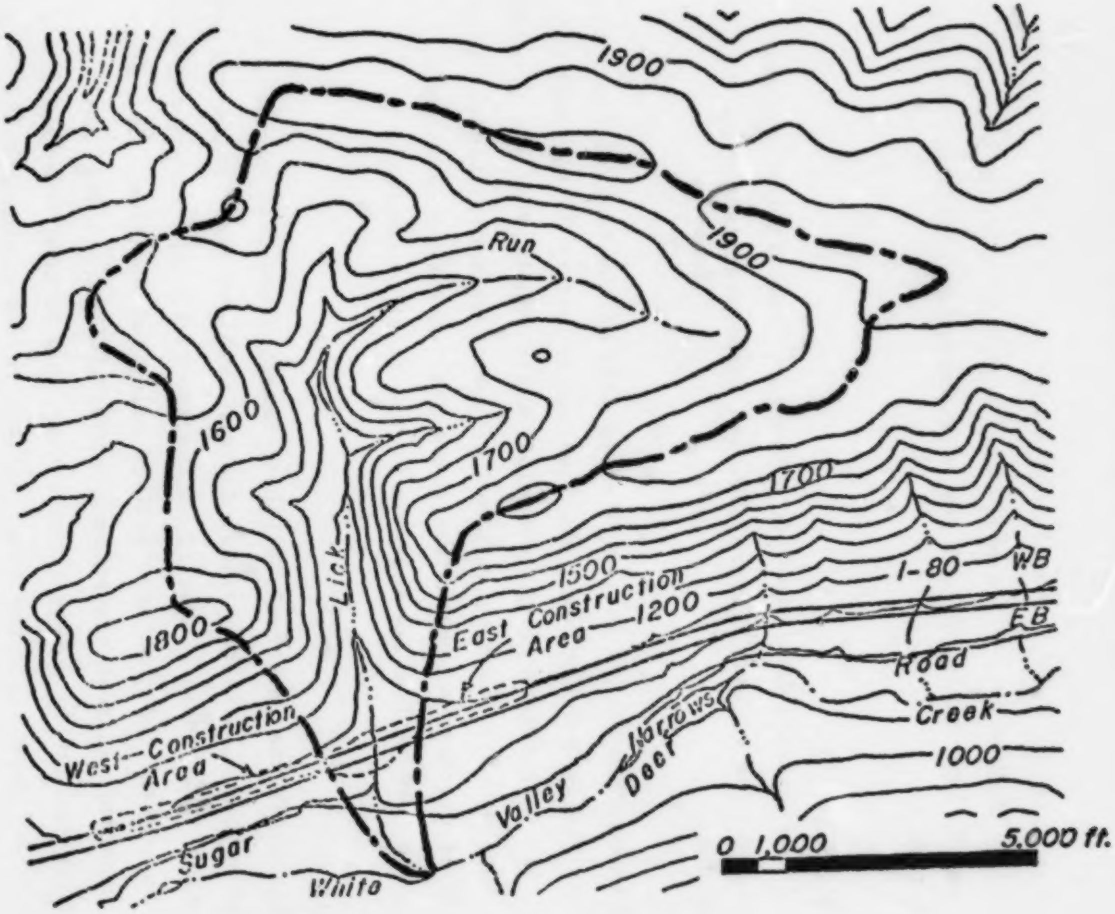
1900
1900
Run
1600
1700
1700
1500
1800
Lick
East Construction
Area
1200
I-80
WB
EB
Road
Creek
1000
West—Construction
Area
Narrows
Deer
Valley
Sugar
White
0 1,000
5,000 ft.

Exhibit 49. Lick Run Drainage Basin and Related Construction Areas (A-48)

Soil Type -
The soil is predominantly a fairly homogeneous Appalachian DeKalb-Lehew-Laidig, stony sandy loam which is derived from grey and brown acid sandstones. This series is of Hydrologic Group C.

Climate/Rainfall -
Rainfall in this part of Pennsylvania is fairly moderate with an average 24 hour storm of 1.11 per year frequency yielding 1.8 inches of rainfall.

Study Method -
The Universal Soil Loss Equation was used to compute the sediment yield, and the various factors involved were determined from the actual field data.

Also under this study, an analysis was made of the comparative costs between the actual treatment which became necessary during I-80 construction with regard to the municipal water supply, and the alternative pollution which would have occurred without treatment. Control by a system of ditches and impoundments was also investigated in terms of cost, and this method was shown to be the least expensive.

Result -
In this study, the Universal Soil Loss Equation was used to compute the sediment yield. The various factors involved were determined from the actual field data. Exhibit 50 represents the hydrograph and sediment concentrations that were derived using the equation. The maximum, recorded sediment concentration was 7,000 mg/l. Sediment yield equaled 256 tons from construction plus 31 tons overland for a total of 287 tons. For the total project in the drainage basin, the sediment yield equaled 1,282 tons (construction--1,024 tons; overland--258 tons), which is 41 percent of the average annual sediment load for the whole watershed of the White Deer Creek area (42 square miles).

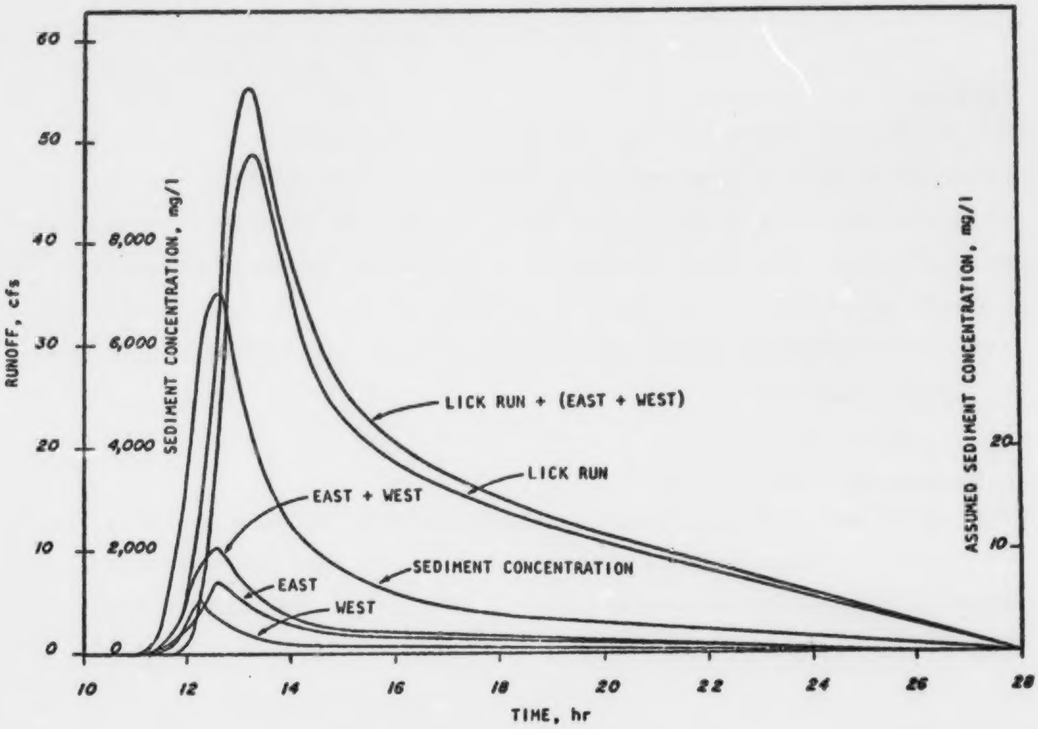

Exhibit 50. Hydrographs and Sediment Concentration Graph, Lick Run Area(A-48)

Case 7. Sediment Discharge in the Lake Tahoe Basin, California: 1972 Water Year

Source-

Carl G. Kroll, Sediment Discharge in the Lake Tahoe Basin, California: 1972 Water Year, Open file Report, U. S. Department of the Interior Geologic Survey, Water Resources Division, Menlo Park, Calif., 1973.(A-34)

Purpose -

The purpose of the study was "to determine the amount of sediment transported from highway cuts in relation to the quantity transported by principal tributaries to the lake." Other objectives were (1) to determine the effects of revegetation and other measures to control erosion at highway cuts, and (2) to "obtain base-line stream flow and sediment--discharge data from selected streams for use in the design of future highways."

Site Location/Description -

The Lake Tahoe drainage basin (excluding a lake surface of 191 mi^2) is 315 mi^2. Lake level is maintained at 6,225 feet above sea level, with the highest point in the basin 10,881 feet. Outflow is controlled by a dam at Tahoe City.

Soil Type -

Soils from the northern parts of the basin are derived from volcanic deposits, while the southern soils are formed from granitic rocks. Glaciation has been a major influence on the landscape and a major source of sediment to the lake. In the past, the lake level has been higher than at present, causing the deposition of alluvial sediments in the shallows at the former margins of the lake. These deposits are presently adjacent to, but above, the lake. They are level and therefore subject to intensive development; they are highly erodible.

Climate/Rainfall -

During the period of this study, October 1971 through September 1972, the precipitation was only 77 percent of the 30-year average from 1931-1960. The precipitation between November and March was 18 inches. During the rest of the year, there were no major storms. Two local showers produced moderate to heavy precipitation of short duration.

Study Method -

Seven gaging stations were installed on stream tributaries to the lake. Water discharge and suspended sediment were measured daily and total sediment discharge was determined periodically. In addition, data were taken from three older gages and from stations set up in highway gutters at 17 locations. The older gaging stations also furnished historical data for comparison with the data being collected.

Results -

Exhibit 51 lists the locations of the stations and gutters from which samples were taken. Exhibit 52 shows a representative daily runoff hydrograph and Exhibits 53 through 58 give samples of the data. Daily data are given in appendices to the reference report. Note that rainfall was below average for this period.

Eighty-seven percent of the annual suspended discharge carried by snowmelt occurred during the early spring. A large sediment source for spring highway runoff is sand that is applied to the roads during the winter. This is of prime importance in the spring and may be significant throughout the year. Suspended sediment discharge is given in Exhibit 55 and 56.

Exhibit 51. SEDIMENT DISCHARGE, LAKE TAHOE BASIN, CALIFORNIA GAGING STATIONS AND GUTTER-FLOW MEASURING INSTALLATIONS(A-34)

(Stations are listed in downstream order with the same numbering system used in water-supply papers and annual data reports of the Geological Survey. Gutters listed under a gaging station are at sites near the creek in the station name.)

Station number	Station name	Drainage area (mi^2)	Highway milepost[1]
10336593	Grass Lake Creek near Meyers	6.99	(at mouth of creek)
	Gutter		89 ED 1.70
	Do.		1.94
	Do.		2.11
	Do.		2.21
	Do.		2.44
	Do.		2.99
	Do.		4.37
	Do.		4.45
10336600	Upper Truckee River near Meyers	33.1	---
10336610	Upper Truckee River at South Lake Tahoe	54.8	50 ED 76.41
10336630	Eagle Cr near Camp Richardson	6.38	89 Ed 17.13
	Gutter		16.61
	Do.		16.87
10336640	Meeks Creek at Meeks Bay	8.08	89 Ed 24.82
	Gutter		24.49
	Do.		24.65
	Do.		25.44
10336650	Quail Lake Cr at Homewood	.95	89 PL 1.55
	Gutter		1.27
	Do.		1.43
10336660	Blackwood Cr near Tahoe City	11.2	89 PL 3.91
10336684	Dollar Cr near Tahoe City	1.07	28 PL 3.50
	Gutter		3.38
	Do.		3.50
10336780	Trout Cr near Tahoe Valley	36.7	(at Martin Avenue)
10336790	Trout Cr at South Lake Tahoe	40.4	50 ED 77.33

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[1] Numbers are taken from milepost markers along highways. First 2 digits designate highway number; the two letters designate county--ED for El Dorado, PL for Placer; the last series of numbers designates distance in miles from southern boundary of designated county.

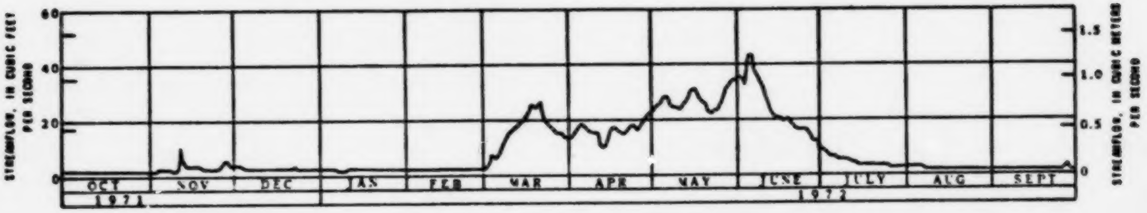

Exhibit 52. Daily Mean Runoff in Grass Lake Creek Near Meyers(A-34)

Exhibit 53. MONTHLY RUNOFF AT SELECTED GAGING STATIONS(A-34)

Station	Runoff (acre-feet)												
	1971			1972									Total[1]
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
Grass Lake Creek near Meyers	123	227	200	164	157	1,010	1,020	1,720	1,480	304	122	127	6,650
Upper Truckee River at South Lake Tahoe	910	1,450	2,370	1,880	1,950	10,700	8,310	17,000	13,700	1,960	686	668	61,600
Eagle Creek near Camp Richardson	41	337	310	202	251	1,580	1,090	4,040	3,530	643	90	117	12,200
Meeks Creek at Meeks Bay	26	100	174	143	286	1,910	1,580	3,600	1,730	82	13	27	9,670
Quail Lake Creek at Homewood	24	37	30	23	18	137	207	612	349	54	12	15	1,520
Dollar Creek near Tahoe City[2]	--	--	--	--	--	--	--	--	12.4	3.9	4.1	6.9	---
Trout Creek at South Lake Tahoe	1,460	1,480	1,520	1,690	1,430	2,580	2,420	4,000	4,340	1,490	899	914	24,200

1. Rounded.
2. Period of record, June through September 1972.

Exhibit 54. MAXIMUM AND MINIMUM WATER DISCHARGE AT GAGING STATIONS (A-34)

Station	Daily mean discharge (ft^3/s)				Instantaneous discharge (ft^3/s)	
	Date	Minimum	Date	Maximum	Date	Maximum
Grass Lake Creek near Meyers	Aug. 26-28, 1972	1.5	June 4-6, 1972	44	June 4, 1972	102
Upper Truckee River near Meyers	Aug. 26	4.4	May 31	299	June 4	402
Upper Truckee River at South Lake Tahoe	Aug. 25, 26, Sept. 22	8.5	June 1	441	June 1	518
Eagle Creek near Camp Richardson	Sept. 25	.23	June 1	112	May 31	128
Meeks Creek at Meeks Bay	Aug. 20-25	.18	May 15	84	May 15	104
Quail Lake Creek at Homewood	Aug. 23-28	.17	May 29	15	May 14, 17	17
Blackwood Creek near Tahoe City	Aug. 27, 28, Sept. 7-9	2.2	May 28	188	May 13	287
Dollar Creek near Tahoe City[1]	July 17,18 Aug. 8,15	.03	June 8, 9	0.38	June 8	0.43
Trout Creek near Tahoe Valley	Aug. 21, 22, 27	12	June 7	94	June 7	100
Trout Creek at South Lake Tahoe	Aug. 20-24, 26-28 Sept. 25	12	June 7	109	June 4	124

1. Period of record, June through September 1972.

Exhibit 55. MONTHLY SUSPENDED-SEDIMENT DISCHARGE AT GAGING STATIONS (A-34)

Station name	Suspended-sediment discharge (tons)													Percent during March-June snowmelt
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total[1]	
Grass Lake Creek near Meyers	0.32	1.6	0.36	0.34	0.40	14	8.8	29	52	1.5	0.52	0.39	109	95
Upper Truckee River at South Lake Tahoe	7.0	58	20	8.0	21	487	165	572	353	9.4	14	5.0	1720	92
Eagle Creek near Camp Richardson	.01	.41	.09	.06	.13	4.6	.78	11	6.6	.43	.06	.74	25	97
Meeks Creek at Meeks Bay	.03	.39	.34	.11	.36	7.5	4.9	31	14	.20	.01	.29	59	97
Quail Lake Creek at Homewood	0	.08	0	0	.03	.51	.63	2.9	1.3	.18	0	.03	6	94
Dollar Creek at Tahoe City 2/	--	--	--	--	--	--	--	--	.01	0	0	0	--	--
Trout Creek at South Lake Tahoe	16	45	18	21	27	108	87	229	387	38	32	29	1040	78

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[1] Values rounded to three significant figures.

[2] Period of record, June through September 1972.

Exhibit 56. MAXIMUM AND SUSPENDED-SEDIMENT DISCHARGE AT SELECTED GAGING STATIONS(A-34)

Station	Daily extremes								Instantaneous Extremes[2]			
	Mean concentration (mg/l)				Mean discharge (tons per day)				Concentration (mg/l)		Discharge (tons per day)	
	Date[1]	Minimum	Date	Maximum	Date[1]	Minimum	Date	Maximum	Date	Maximum	Date	Maximum
Grass Lake Creek near Meyers	Dec. 1971-Feb., Aug., Sept. 1972	1	June 4, 1972	113	Aug., Sept 1972	0	June 4, 1972	22	June 4, 1972	500	June 4, 1972	124
Upper Truckee River at South Lake Tahoe	Dec. 1971, Jan., July-Sept. 1972	2	Mar 3, 1972	200	Aug., Sept. 1972	.05	Mar. 3	87	Aug. 30	590	Mar. 3	159
Eagle Creek near Camp Richardson	Nov. 1971-Apr., June-Aug. 1972	0	Mar. 3, 1972	20	Oct. 1971-Apr., June-Sept. 1972	0	Mar. 3	1.5	Mar. 3	35	Mar. 3	3.3
Meeks Creek at Meeks Bay	Dec. 1971-Feb. 1972	0	Sept. 1, 1972	31	Oct. 1971-Feb., July-Sept. 1972	0	May 15	2.5	Sept. 1	150	Apr. 5	4.3
Quail Lake Creek at Homewood	Dec. 1971-Jan. 1972	0	Sept. 26, 1972	11	Oct. 1971-Mar., July-Sept. 1972	0	June 1	.21	Sept. 26	23	June 1	38
Dollar Creek near Tahoe City[3]	Sept. 1972	1	July 4,5, 1972	7	June-Sept. 1972	0	June 8	.01	Aug. 16	18	Aug. 16	02
Trout Creek at South Lake Tahoe	Sept. 25, 1972	3	Aug. 30, 1972	186	Sept. 25, 1972	.10	June 4	51	Aug. 30	730	June 4	137

1. Minimum daily mean extremes occurred more than once when specific day is not indicated.

2. Estimated from temporal concentration curve.

3. Period of record, June through September 1972.

Exhibit 57. SUSPENDED SEDIMENT AND PARTICLE SIZE AT SELECTED GAGING STATIONS(A-34)

Date	Time (Hours)	Water temper-ature (°C)	Water Discharge (ft^3/s)	Suspended sediment		Particle size					Method of analysis
				Concen-tration (mg/l)	Discharge (tons per day)	Percent finer than size (in millimeters) indicated					
						0.062	0.125	0.250	0.500	1.00	
				Upper Truckee River at South Lake Tahoe							
Nov. 11, 1971	1520	--	52	270	38	99	100	--	--	--	Sieve
Apr. 10, 1972	1230	6.0	116	3	.94	68	--	--	--	--	Do.
May 8	2355	--	276	14	10	39	--	--	--	--	Do.
May 12	1400	9.5	226	11	6.7	50	50	100	--	--	Do.
May 17	1420	9.5	318	13	11	36	50	80	100	--	Do.
June 13	0850	9.0	188	15	7.6	39	44	70	100	--	Do.
June 16	1400	14.0	166	19	8.5	22	27	52	94	100	Do.
				Trout Creek at South Lake Tahoe							
Mar. 4, 1972	1415	7.5	43	38	4.4	35	49	69	100	--	Do.
Apr. 10	1240	6.5	36	7	.68	19	20	36	93	100	Do.
May 9	0015	--	61	26	4.3	51	58	83	100	--	Do.

Exhibit 58. PARTICLE SIZE OF BED MATERIAL AT SELECTED GAGING STATIONS(A-34)

Date	Time (Hours)	Water temperature (°C)	Number of sampling points	Water Discharge (ft^3/s)	Particle size									Method of analysis
					Percent finer than size (in millimeters) indicated									
					0.125	0.250	0.500	1.00	2.00	4.00	8.00	16.0	32.0	
Upper Truckee River at South Lake Tahoe														
May 12, 1972	1450	9.5	4	218	1	7	28	38	53	75	96	100	--	Sieve
July 3	1140	14.5	5	62	1	7	22	35	47	65	90	99	100	Do.
Trout Creek at South Lake Tahoe														
April 10	1240	6.5	2	36	--	2	22	44	53	77	100	--	--	Do.
May 3	1300	--	2	55	--	2	26	55	80	95	100	--	--	Do.

APPENDIX B: EFFECTS OF URBAN CONSTRUCTION ON WATER QUALITY

This appendix summarizes 11 case studies that contain data on the effects of urban-area construction on water quality. Data from the studies are included in the summaries. For clarity, each case study begins on a separate page. See Appendix G for List of References.

Case 8. Effects of Urbanization in the Colma Creek Basin, California

Source -

Knott, J. M., Effects of Urbanization on Sedimentation and Flood Flows in Colma Creek Basin, California, Open File Report, U. S. Geological Survey, Menlo Park, California, February 22, 1973.(A-32)

Purpose -

This study was undertaken "to document the water and sediment discharge of streams in the basin during periods of active development, and to estimate the probable effect of urbanization on flood flows and sediment yield." Special emphasis was placed on the quantities of sand transported by the creek, since this tends to deposit in the lower reaches of the creek and contributes to flooding.

Site Location/Description -

"Colma Creek, a tributary to San Francisco Bay, drains a 16.3 square-mile area on the east side of the San Francisco Peninsula. The basin is bounded on the northeast by San Bruno Mountain and on the west by the ridge traced by Skyline Boulevard. Elevations range from sea level at the mouth of Colma Creek to more than 1,300 feet above mean sea level on the San Bruno Mountain." (See Exhibit 59)

Topography -

"Dominant topographic features of the drainage basin include two relatively straight mountain ridges that diverge toward the southeast and are connected by a low ridge at the northern boundary of the area. The valley enclosed by the ridges widens toward the southeast where it drains into San Francisco Bay.

"Most of the population of the area is centered in the cities of Daly City and South San Francisco. The remaining population is divided among Colma, Pacifica, and San Bruno."

Source: Knott, J. M. (1973)

Exhibit 59. Aerial Photograph of the Colma Creek Basin (1971). Drainage Divide is Indicated Approximately by Line (A-32)

Soil Types -

Soil types are tabulated in Exhibit 60.

Vegetation -

"Vegetal cover consists primarily of lawns, parks, and native grasses in urban and foothill areas, and chaparral at higher elevations in the undeveloped areas. Exotic trees and shrubs, although present in many varieties, cover a small part of the basin. Flowers and vegetables are grown commercially in areas adjacent to Colma Creek and in foothill areas adjacent to San Bruno Mountain."

Land Use -

"In 1946, about 70 percent of the land in the Colma Creek basin was used for agriculture or was undeveloped. About half of the remaining land was set aside for open spaces (cemetaries and parks) and half was developed (urban and industrial). Most of the urban and industrial areas were located near the mouth of Colma Creek where harbor facilities were available.

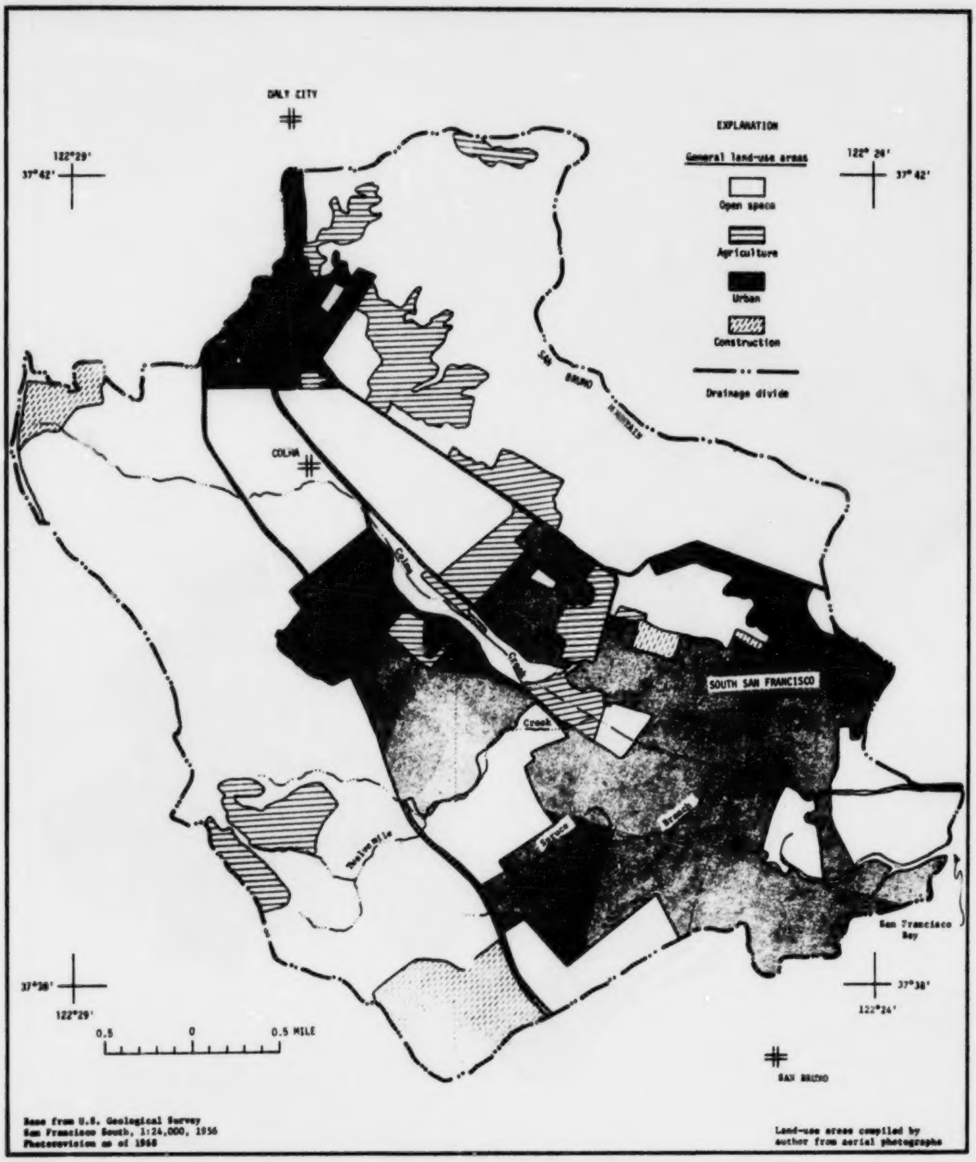
"After 1950, urbanization progressed along the flatter valley lands between South San Francisco and Daly City. By 1956, 34 percent of the basin was urbanized, 51 percent was undeveloped, 12 percent was agriculture, and 3 percent was under construction (Exhibit 61). During the next decade (1971-1980) construction and open space areas are expected to be reduced and urban areas are expected to increase. Land use during the latter part of the decade is expected to be about 62 percent urban, 35 percent open space, and 3 percent agriculture." (Exhibit 62).

Parameters Measured -

- Rainfall
- Water discharge (from basin and component sub-basins)

Exhibit 60. CHARACTERISTICS OF SOILS OCCURRING IN THE COLMA CREEK BASIN(A-32)

Soil association	No.	Profile			Topography	Land slope (percent)	Erosion hazard
		Surface	Subsoil	Parent material			
Tunitas-Lockwood	1	Clay loam, loam	Clay, clay loam	Sedimentary alluvium	Gently sloping fans	0-5	None to slight
Sunnyvale-Castro	2	Silty clay, clay	Silty clay, clay	Clay alluvium	Level, low valley bottoms	≥0	None
Elkhorn-Colma	3	Sandy loam	Sandy clay loam, loam	Coastal sediments, marine sediments	Terraces	5-15	Slight to moderate
Tierra-Colma	4	Sandy loam	Sandy clay, loam	Coastal sediments, marine sediments	Terraces	9-15	Moderate
Tierra-Colma	5	Sandy loam	Sandy clay, loam	Coastal sediments, marine sediments	Terraces	15-30	High
Los Gatos-Hulls	6	Loam	Clay loam, loam	Sandstone and shale, sandstone and chert	Hilly, mountainous	30-50	High
Gaviota-Rockland	7	Loam, sandstone and shale	Loam, sandstone and shale	Sandstone and shale	Mountainous	30-70	High
Sweeney-Mindego	8	Clay loam	Sandy clay loam, clay	Basic igneous rock, basalt	Mountainous	30-70	High
Made soils, over bay muds	9	Sand, silt, clay, and crushed rock	Sand, silt, clay, and crushed rock	Clay	Tidal marshes	≥0	None
Made soils	10	(Variable textured unconsolidated material)			Benched hills	--	High


DALY CITY
EXPLANATION
General land-use areas
Open space
Agriculture
Urban
Construction
Drainage divide
122°29'
37°42'
122° 24'
37° 42'
SAN BRUNO MOUNTAIN
COLMA
Colma
Creek
SOUTH SAN FRANCISCO
Creek
Spruce
Branch
Twelve Mile
San Francisco Bay
37°38'
122°29'
37°38'
122°24'
0.5
0
0.5 MILE
SAN BRUNO

Base from U.S. Geological Survey
San Francisco South, 1:24,000, 1956
Photorevision as of 1968

Land-use areas compiled by
author from aerial photographs

Exhibit 61. Generalized Land Use in the
Colma Creek Drainage Basin, 1956(A-32)

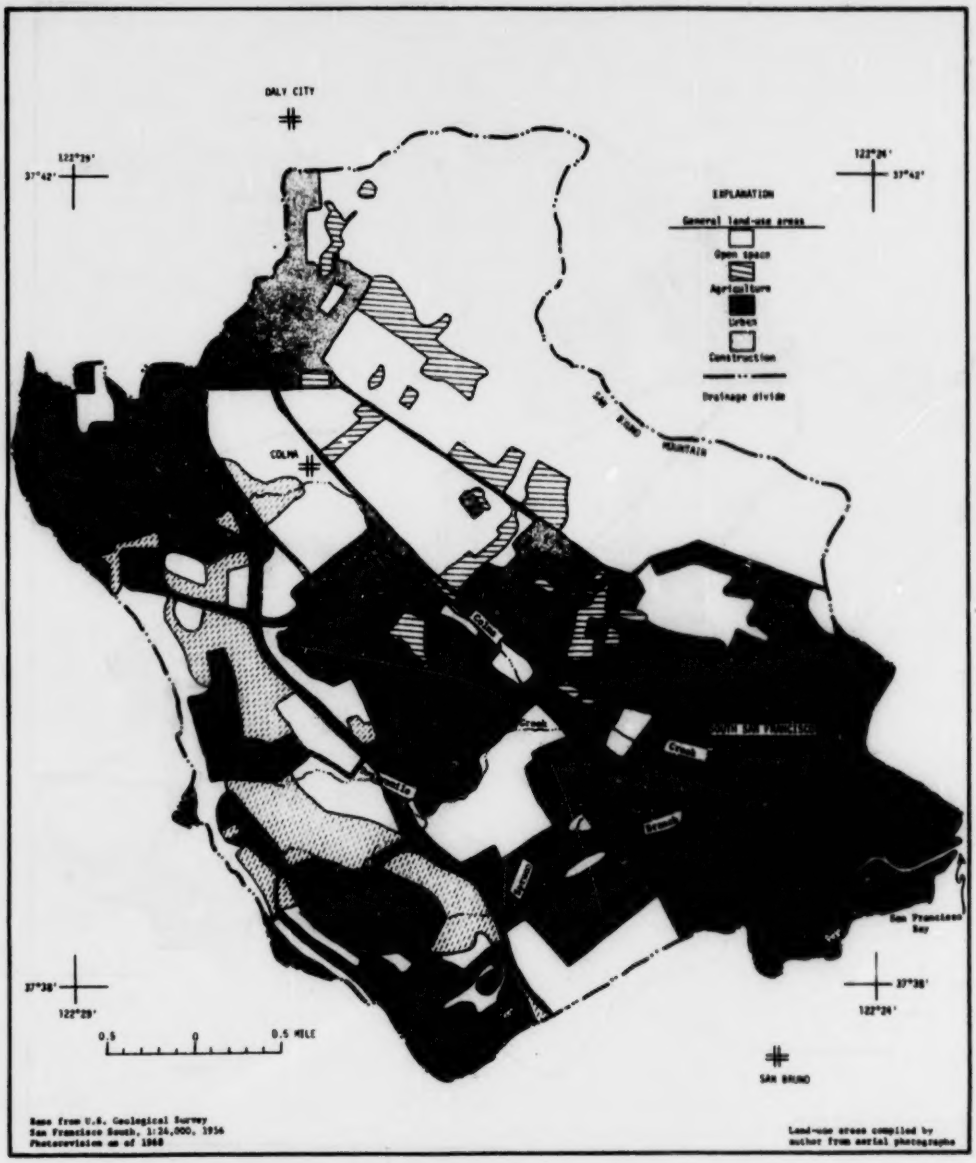

DALY CITY
122°29'
37°42'
122°24'
37°42'
EXPLANATION
General land-use areas
Open space
Agriculture
Urban
Construction
Drainage divide
SAN BRUNO MOUNTAIN
COLMA
Colma
Creek
SOUTH SAN FRANCISCO
Creek
Branch
San Francisco Bay
37°38'
122°29'
37°38'
122°24'
0.5
0
0.5 MILE
SAN BRUNO
Base from U.S. Geological Survey
San Francisco South, 1:24,000, 1956
Photorevision as of 1968
Land-use areas compiled by
author from aerial photographs

Exhibit 62. Generalized Land Use in the Colma Creek Drainage Basin, 1970(A-32)

- Concentration of suspended sediment in discharges
- Sediment deposited in debris basins (surveyed by transit-stadia transverse or prismoidal methods)
- Constituents of suspended sediment discharged (sand, clay-silt)
- Land use (from aerial photographs)

Study Method -

The above listed parameters (except land use) were measured at the locations shown in Exhibit 63.

Measurement data for the above listed parameters were used to determine quantities of water discharge and sediment yield per square mile of the entire basin and certain sub-areas.

Quantities of suspended sediment in runoff were computed from the measured quantities of water discharged, concentrations of sediment in the discharged water, and specific gravity of the sediment.

Sediment yield for various types of land use was estimated by prorating the annual sediment discharge at a particular (downstream) measurement station. The prorating procedure takes into account: (1) the percentage of land in each use category (urban, open space, agriculture, and construction) in the area drained by the stream above the measuring station; and (2) an index of sediment yield for each land use category.

The study also projected future yields of sediment from the basin at such time as the basin was fully urbanized (defined as 65 percent urban, 35 percent open space). Under these conditions, the total yield is expected to be lower than the 1971 yield because of the reduction in exposed soil for construction and agricultural purposes.

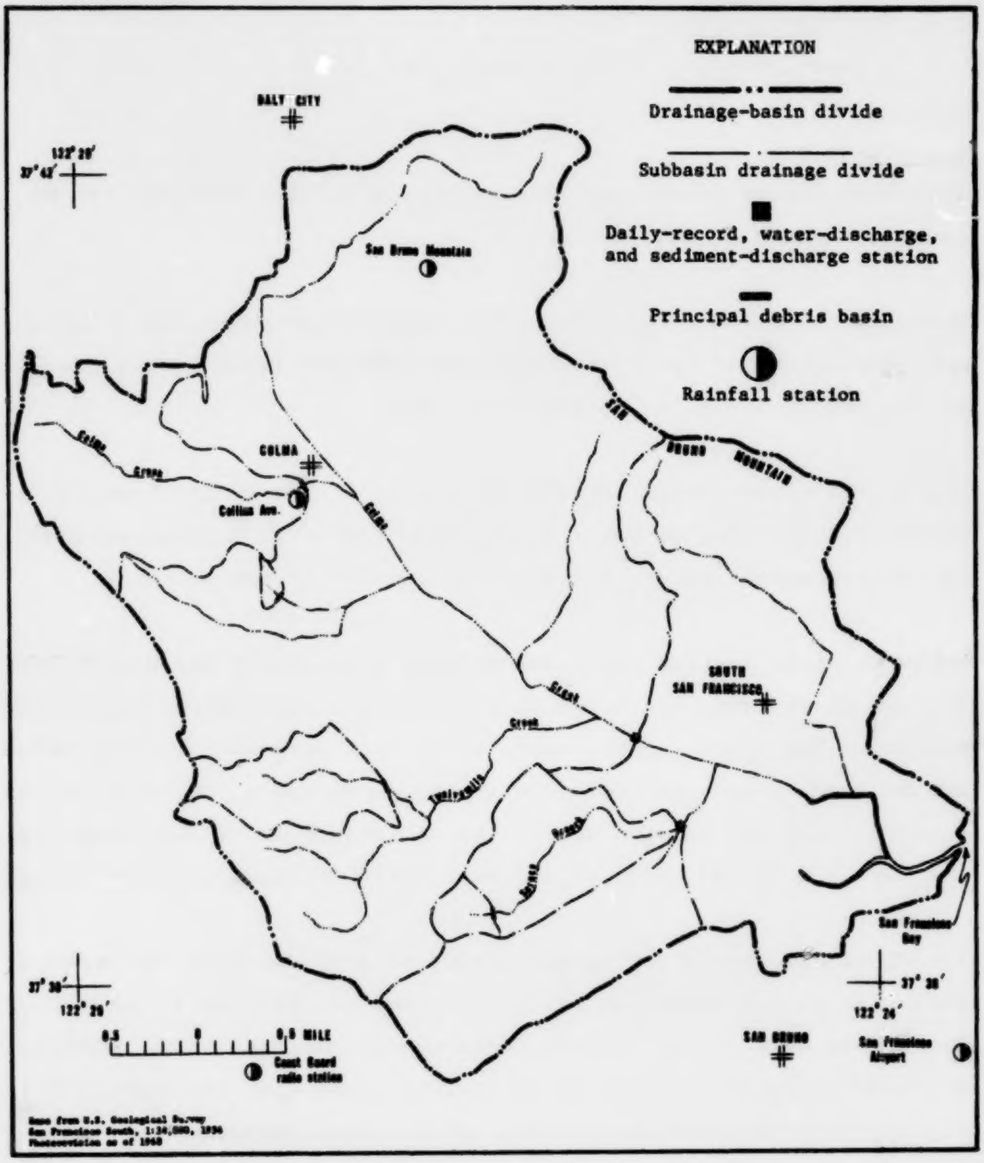

EXPLANATION
Drainage-basin divide
Subbasin drainage divide
■ Daily-record, water-discharge, and sediment-discharge station
Principal debris basin
◑ Rainfall station
DALY CITY
122°28'
37°42'
San Bruno Mountain
COLMA
Colma Creek
Collins Ave.
Colma
SAN BRUNO MOUNTAIN
SOUTH SAN FRANCISCO
Creek
Creek
Twelvemile
Spruce Branch
San Francisco Bay
37°38'
122°28'
0.5 0 0.5 MILE
Coast Guard radio station
SAN BRUNO
37°38'
122°24'
San Francisco Airport
Base from U.S. Geological Survey
San Francisco South, 1:24,000, 1956
Photorevision as of 1968

Exhibit 63. Hydrologic Data Stations in the Colma Creek Basin(A-32)

Time Frame -

The study was based on records of stream flow, sediment, and land use data acquired during the interval 1964 - 1971 when the basin was undergoing rapid urbanization.

Results -

Rainfall: Precipitation data were available from measurement stations at four locations in or near the basin. Historical data at one location and short-term data at three locations are summarized in Exhibit 64.

Water Discharge: Runoff data at two locations are summarized in Exhibit 65. This information for certain time periods is related to changes in land use in Exhibit 66, which indicates the changing fraction of rainfall discharged as runoff.

Exhibits 67 and 68 show time and quantity relations between rainfall intensity and rate of runoff.

Sediment Discharge: Sediment concentration and water discharge rate were measured concurrently at two locations. Suspended sediment transported past the gaging stations at these locations was calculated by the relation:

$$A_s = KC_sQ_w$$

where

A_s is the sediment discharge, in tons per day

K is a constant (equivalent to 0.0027 for sediment having a specific gravity of 2.65)

C_s is the concentration of suspended sediment, in milligrams per liter

Q_w is the water discharge, in cubic feet per second

EXHIBIT 64

SUMMARY OF PRECIPITATION DATA IN THE COLMA CREEK BASIN(A-32)

Station location	Period of record (water Year)	Elevation above mean sea level (feet)	Average annual precipitation (inches)	Range in monthly precipitation (inches)	Station location	Period of record (water year)	Elevation above mean sea level (feet)	Average annual precipitation (inches)	Range in monthly precipitation (inches)
San Francisco Airport near South San Francisco[a]	1927-70	8	[b]18.69	0.00-12.30	Collins Avenue maintenance yard at Colma[c]	1965-70	170	[d]22.5	0-10.8
	1964		12.72	Trace-4.38					
	1965		20.80	Trace-5.42					
	1966		17.65	Trace-5.40	Coast Guard radio station near Pacifica	Dec.1968-Feb.1971	930	24.1	0-9.6
	1967		30.75	Trace-10.43					
	1968		15.88	Trace-5.25					
	1969		28.24	Trace-8.92	San Bruno Mountain near Colma	Oct.1970-Feb.1971	970	—	0-4.7
	1970		19.56	Trace-8.33					
	1971		18.71	Trace-6.41					
	1964-71		20.33	Trace-10.43					

[a] U.S. Weather Bureau Station.

[b] Standard normal precipitation (1931-60).

[c] Records maintained by San Mateo County subsequent to December 1968.

[d] Includes precipitation data for Christen Ranch (1961-65).

Exhibit 65. WATER DISCHARGE OF COLMA CREEK AND SPRUCE BRANCH AT SOUTH SAN FRANCISCO(A-32)

Station	Drainage area (sq mi)	Water year(s) (Oct.1 to Sept.30)	Water discharge			
			Annual		Maximum	
			Cfs-days	Acre-feet	Daily (cfs)	Instantaneous (cfs)
Colma Creek at South San Francisco	10.8	1964	853	1,690	236	1,050
		1965	2,040	4,060	113	671
		1966	1,700	3,360	160	318
		1967	3,640	7,220	462	1,120
		1968	1,920	3,800	198	1,260
		1969	3,890	7,710	162	1,180
		1970	2,900	5,750	205	918
		1971	2,750	5,450	203	1,980
		1964-71	2,460	4,880	--	-
Spruce Branch at South San Francisco	1.68	[1]1966	416	825	43	219
		1967	740	1,470	113	372
		1968	364	722	60	389
	.70	[2]1969	304	603	13	137

[1] Water discharge records began February 20, 1965.

[2] Station discontinued September 30, 1969.

Exhibit 66. RAINFALL, RUNOFF, AND LAND USE DURING NOVEMBER TO MARCH STORM SEASONS, 1964-71(A-32)

Water year	Rainfall (inches)	Runoff (inches)	Ratio of runoff to rainfall	Land use (percent)[a]			
				Open space	Urban	Agriculture	Construction
1964	10.44	2.58	0.25	--	[b]34	--	--
1965	15.78	5.28	.33	--	--	--	--
1966	16.89	5.38	.32	--	--	--	--
1967	24.31	9.52	.39	42	38	5	15
1968	14.51	5.10	.35				
1969	25.84	11.24	.43	41	40	5	14
1970	17.01	7.58	.45	42	46	4	8
1971	16.83	7.30	.43	--	--	--	--

[a] Upstream from Colma Creek gaging station

[b] Interpolated from land-use data determined for 1956 and 1967.

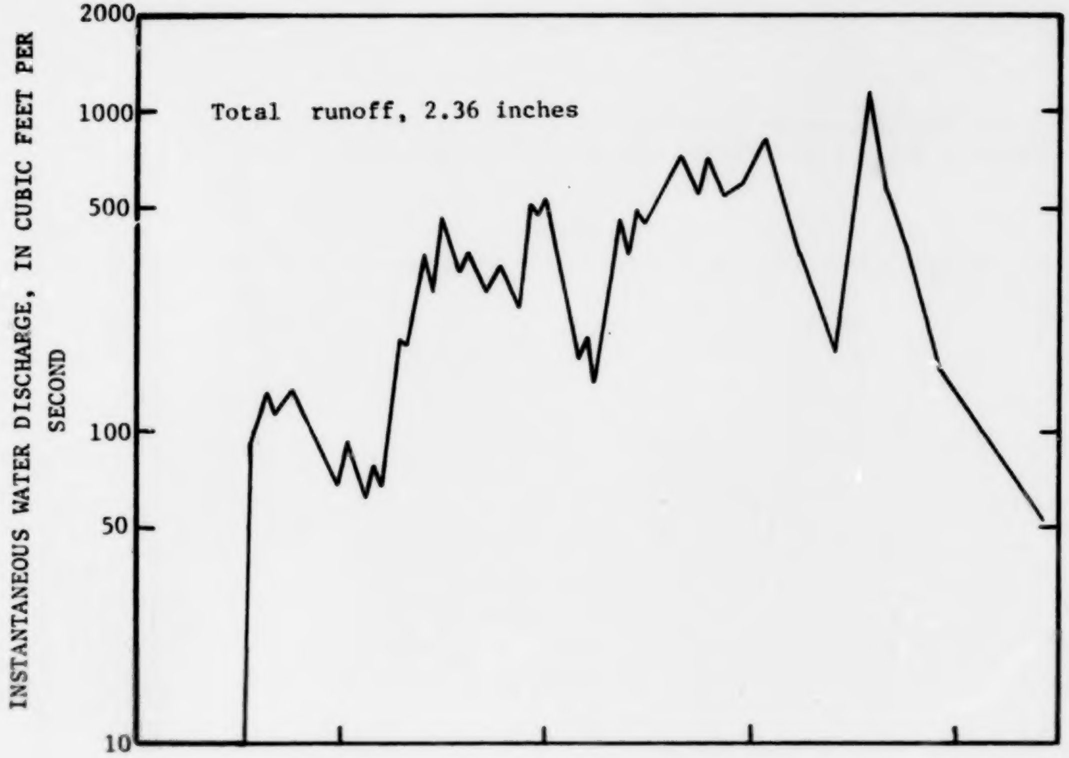


Exhibit 67. Relation Between Water Discharge and Time During Storm of January 20-21, 1967(A-32)

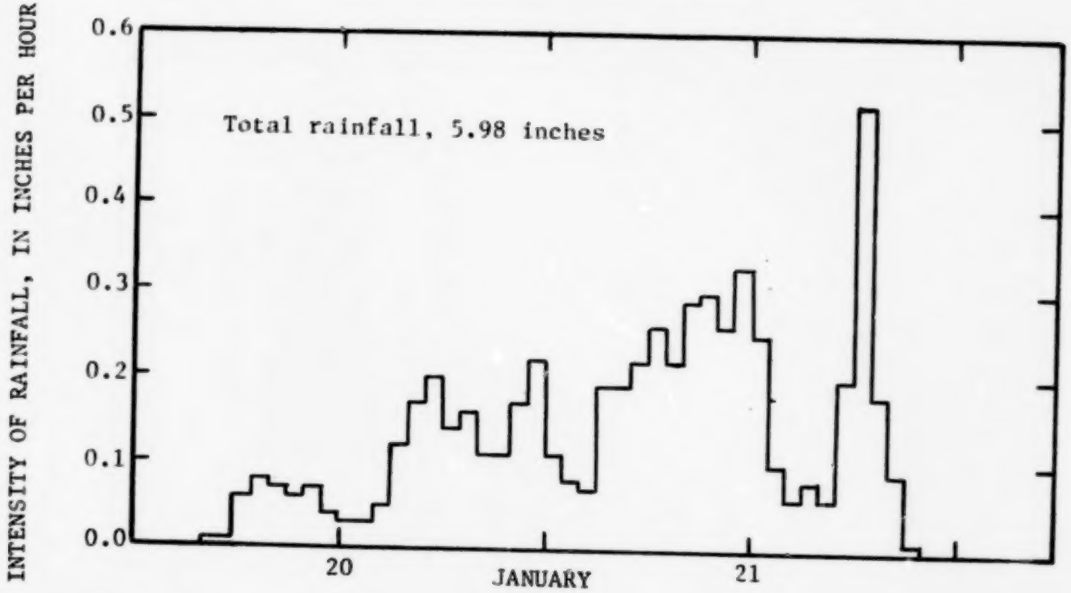


Exhibit 68. Water Discharge at Colma Creek Gaging Station and Rainfall at San Francisco Airport During the Storm of January 20-21, 1967(A-32)

Results are presented in Exhibit 69. The reported values of sediment transported do not include bedload, which is stated to constitute only a small fraction of the total sediment load.

Substantial proportions of the sediment were trapped in debris basins, the number of which in use during any given year varied from 5 to 10 during the study period. Quantities trapped were determined by surveys of certain basins. The trapped sediment consisted primarily of sand (e.g., in one location, sand constituted 59 percent, silt-clay 41 percent). During a single year, one debris basin above the Colma Creek measurement station prevented some 12,300 tons of sediment from reaching the station. This compares with 65,100 tons transported past the station during the same period.

Total sediment yield from specific areas were determined by combining the measured quantities transported by measurement stations plus the quantities retained by debris basins. Total yields, determined in this manner, are shown in Exhibit 70.

Sediment Discharge from Specific Types of Land Use. - "The annual quantity of sediment transported from various land-use areas was computed by prorating the annual sediment yields at the Colma Creek gaging station during 1969 and 1970 on the basis of sediment yield indexes characteristic of moderate-to-large storms and the distribution of land use upstream from the gaging station. Because index data were comparable for different storm sizes, a series of composite sediment-yield indexes was assigned for average sediment-transport conditions. (See Exhibit 71).

Exhibit 69. WATER AND SEDIMENT DISCHARGE OF COLMA CREEK AND SPRUCE BRANCH AT SOUTH SAN FRANCISCO(A-32)

Streamflow and sediment station	Drainage area (sq mi)	Water year (Oct. 1 to Sept.30)	Water discharge		Suspended sediment						TOTAL SUSPENDED SEDIMENT	
			Annual (cfs-days)	Maximum day (cfs)	Total		Sand		Maximum day (tons)		Ratio to H_2O Discharge	
					Discharge (tons)	Mean concentration (mg/l)	Discharge (tons)	Mean concentration (mg/l)	Total	Sand	Discharge (tons)	Concentration (mg/l)
Colma Creek at South San Francisco	10.8	1966	1,700	160	32,100	6,990	[1]11,800	2,570	5,790	[1]2,480	19	•
		1967	3,640	462	122,000	12,400	[1]60,800	6,190	27,000	[1]14,800	34	
		1968	1,920	198	35,700	6,890	18,800	3,630	7,890	4,810	18.5	
		1969	3,890	162	65,100	6,200	34,200	3,260	4,290	2,610	16.7	
		1970	2,900	205	24,900	3,180	14,300	1,830	5,560	3,590	8.4	
Spruce Branch at South San Francisco	1.68	1966	416	43	4,760	4,240	2,220	1,980	854	523	11.3	10.2
		1967	740	113	9,800	4,900	5,580	2,790	2,300	1,400	13.	6.6
		1968	364	60	[3]39,300	[3]40,000	-	-	-	-	108.	110.
	[2].70	1969	304	13	[3]27,000	[3]32,900	-	-	-	-	89.	105.

[1] Revised from Knott (1969).

[2] Drainage area reduced by upstream diversion.

[3] Result of highway construction, real estate development, and ineffective debris basin.

Exhibit 70. TOTAL SEDIMENT YIELD OF THE BASIN UPSTREAM FROM THE COLMA CREEK GAGING STATION INCLUDING SEDIMENT TRAPPED IN UPSTREAM DEBRIS BASIN, 1966-70(A-32)

Water year (Oct. 1 to Sept. 30)	Annual sediment yield					
	Total		Sand		Silt clay	
	Tons	Tons per sq mi	Tons	Tons per sq mi	Tons	Tons per sq mi
1966	45,300	4,190	21,600	2,000	23,700	2,190
1967	153,000	14,200	81,300	7,530	71,300	6,600
1968	47,500	4,400	27,700	2,560	19,800	1,830
1969	82,500	7,640	46,500	4,310	36,000	3,330
1970	36,800	3,410	23,300	2,160	13,500	1,250

Exhibit 71. SEDIMENT YIELD INDICES FOR VARIOUS LAND USES AND SEDIMENT PARTICLE SIZES(A-32)

Land use	Sediment transported	Sediment yield index
Open space	Sand	1.0
Urban	Sand	2.2
Agriculture	Sand	70
Construction	Sand	70
Open space	Silt - clay	1.0
Urban	Silt - clay	3.0
Agriculture	Silt - clay	60
Construction	Silt - clay	120
Open space	Total	1.0
Urban	Total	2.4
Agriculture	Total	65
Construction	Total	85

"Annual yields from land-use areas were computed from the equation:

$$Y_{(o,u,a,c)} = \frac{XI_{(o,u,a,c)}P_{(o,u,a,c)}}{I_oP_o+I_uP_u+I_aP_a+I_cP_c}$$

where

Y = the annual sediment yield from a specific land-use area, in tons
X = the annual yield at the Colma Creek gaging station, in tons
I = the sediment yield index
P = the percentage of a specific land use upstream from the gaging station

The subscripts o, u, a, and c refer to the type of land use (open space, urban, agriculture, or construction)." These annual yields are given in Exhibit 72.

"Construction areas, representative of 14 percent of the basin, contributed 59,000 tons or 72 percent of the sediment transported from areas upstream from the Colma Creek gaging station in 1969. About 17,000 tons of sediment transported from these areas were trapped in debris basins. Agricultural areas contributed 16,000 tons of sediment (20 percent), none of which was deposited in debris basins. Urban and open-space areas, representative of 81 percent of the basin, contributed 6,800 tons of sediment or about 8 percent of the total sediment yield.

"In 1970, sediment yield from all areas was less than in 1969 because of reduced storm activity. Construction areas contributed 23,000 tons of sediment, of which about 12,000 tons was trapped in debris basins.

Exhibit 72. ANNUAL SEDIMENT YIELDS FROM DIFFERENT LAND-USE AREAS UPSTREAM FROM THE COLMA CREEK GAGING STATION (A-32)

Year	Land use		Sediment yield					
			Total		Sand		Silt-clay	
	Type	Percent	Tons	Tons per sq mi	Tons	Tons per sq mi	Tons	Tons per sq mi
1969	Open space	41	2,000	452	1,310	296	689	156
	Urban	40	4,820	1,120	2,800	648	2,020	468
	Agriculture	5	16,190	30,000	11,150	20,600	5,040	9,330
	Construction	14	59,470	39,300	31,230	20,600	28,240	18,700
	Total[1]	100	82,500	7,640	46,500	4,310	36,000	3,330
1970	Open space	42	1,410	311	995	219	411	91
	Urban	46	3,750	755	2,400	483	1,350	272
	Agriculture	4	8,990	20,800	6,640	15,400	2,350	5,440
	Construction	8	22,660	26,200	13,270	15,400	9,390	10,900
	Total[1]	100	36,800	3,410	23,300	2,160	13,500	1,250

[1] Computed from other data in this case study.

Of the remaining sediment yield upstream from the Colma Creek gaging station, agricultural, urban, and open-space areas contributed 9,000, 2,800, and 1,400 tons, respectively."

Comparison of Estimated Sediment Yield from Open-Space Areas with Sediment Yields from Selected Nearby Streams. - "The validity of sediment-yield estimates from open-space areas in the Colma Creek basin was tested by comparing sediment yields for 1967, 1969, and 1970 (years when land-use percentages were determined) with concurrent data for sediment stations on streams in the San Francisco Bay area which are relatively undeveloped (Exhibit 73). Estimated sediment yields fall within the range of yields for other bay area streams, but large variations in runoff suggest that rainfall characteristics are quite different and that storm events may not be related. It is assumed that estimated yields are reasonable."

Exhibit 73. COMPARISON OF SEDIMENT YIELD FROM OPEN-SPACE AREAS IN THE COLMA CREEK BASIN WITH SEDIMENT YIELDS FROM SELECTED BAY AREA STREAMS(A-32)

Year	Sediment station	Drainage area (sq mi)	Runoff (acre-feet per sq mi)	Sediment yield (tons per sq mi)
1967	Uvas Creek above Uvas Reservoir, near Morgan Hill	21	1,020	2,290
	Coyote Creek near Gilroy	109	320	721
	Arroyo Valle near Livermore	147	155	1,000
	Alameda Creek near Niles	633	112	[a]454
	Open-space areas in Colma Creek basin	4.6	[b]669	780
1969	Uvas Creek above Uvas Reservoir, near Morgan Hill	21	1,820	1,140
	Coyote Creek near Gilroy	109	868	1,540
	Alameda Creek near Niles	633	174	[a]256
	Open-space areas in Colma Creek basin	4.4	[b]714	452
1970	Uvas Creek above Uvas Reservoir, near Morgan Hill	21	1,020	580
	Coyote Creek near Gilroy	109	328	179
	Alameda Creek near Niles	633	91.8	[a]137
	Open-space areas in Colma Creek basin	4.6	[b]532	311

[a] Yield reduced by reservoirs.

[b] Runoff per square mile at Colma Creek gaging station.

Case 9. Residential Construction and Sedimentation at Kensington, Maryland

Source -

Guy, H. P. "Residential Construction and Sedimentation at Kensington, Maryland" Proceedings of Federal Inter-Agency Conference, 1963, Miscellaneous Publication No. 920, USDA Agricultural Research Service, June 1965.(A-19)

Purpose -

The purpose of this study was to investigate the relation between sediment yield and construction activities in an 20-acre tract being transformed from rural to residential use. The tract is located within a drainage basin of 58 acres, much of which had previously been developed for residential use.

Site Location/Description -

Selected for this study was a 58-acre drainage area in Kensington, Maryland, a suburb northwest of Washington, D. C.

Topography -

Natural slopes range from 3 to 10 percent; artificial slopes range from 3 to 25 percent.

Soil Type -

An average of two subsoil samples shows 14 percent clay, 30 percent silt, 43 percent sand, 13 percent gravel; a very friable soil and subsoil.

Climate/Rainfall -

Typical of mid-Atlantic coastal states, the rainfall is about 42 inches per year. Stream runoff averages about 16 inches, of which 4 inches is surface runoff.

Land Use/Ground Cover -

This area is largely residential.

Study Method -

Most of the 58-acre watershed was developed for residential use during the period July 1957 through April 1962. Measurements of rainfall, runoff, and suspended sedimentation were taken during construction of 89 houses on a 20.5 acre tract within the watershed during the interval July 1957 through January 1962. Measurement of these parameters within the watershed was made during 25 specific storm events, although continuous measurements of water discharge are available for Rock Creek, to which the watershed undergoing development is a tributary. Sediment concentrations in the runoff from the watershed during unmeasured storms were estimated by correlation with water discharge from Rock Creek.

Construction was performed in stages. Subareas ranging in size from 5 to 20 houses were developed, and as many as 3 subareas were exposed at a time. Some subareas were exposed for only 8 months while others were exposed as long as 2 years.

Layout of streets in the development was irregular. One street is in the main drainageway of the upper part of the basin, where the 20-acre tract undergoing construction was located.

Detailed data (rainfall, streamflow, sediment discharge) are reported for one major storm event, and summary data are given for all 25 storms during the study period. In addition, estimates of sediment concentration are presented for storm events.

Parameters Measured -

- Rainfall

- Sediment concentration as discharge (from watershed) was obtained from depth integrated samples; these samples were sieved to size distribution
- Water discharge (from watershed)
- Water dischrage (from Rock Creek)
- Amount of area under construction (from aerial photograph)

Results -

Detailed data were reported for a single heavy storm, and summary data were reported for 25 storm events. In addition, estimates of sediment concentrations during other events were computed by use of a model that correlates sediment discharge with flow conditions in Rock Creek, which is monitored continuously.

Single-storm data are presented in Exhibits 74 (suspended sediment graph and runoff hydrograph); Exhibit 75 (tabulation of runoff discharge, sediment concentration, and sediment discharge during short intervals throughout the storm); and Exhibit 76 (total and peak intensity of rainfall, streamflow, and sediment discharge).

Data covering major storms that occurred during the entire study period are presented in Exhibit 77 (precipitation, water discharge, sediment discharge, and concentration, and air temperature). Observed sediment concentration as well as computed estimates are shown plotted against time in Exhibit 78. Cumulative sediment discharged from the construction area is shown plotted against time in Exhibit 79.

The referenced article states that the sediment yield from the construction area averaged 189 tons/acre (121,000 tons/sq. mi.) during the period of construction and return to stable conditions. This amounts to some 2.1 tons per dwelling unit constructed.

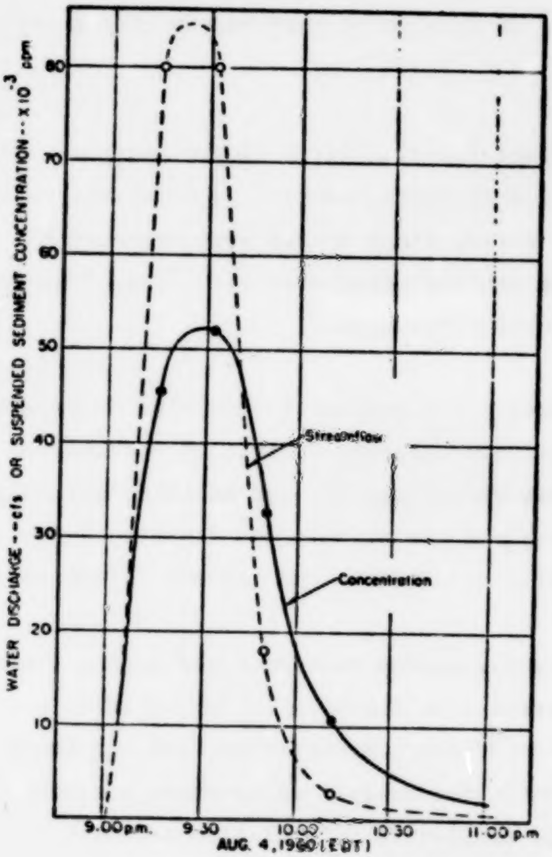


Exhibit 74. Runoff Hydrograph and Suspended-Sediment Concentration Graph for Storm of August 4, 1960, on 58-Acres at Kensington, Maryland (A-19)

Exhibit 75. Subdivision and Computation of Water and Sediment Discharge for Storm the Evening of August 4, 1960$^{(A-19)}$

Time (p.m.)	Interval	Runoff discharge	Sediment	
			Concentration	Discharge
	Hour	*C.f.s.*	*P.p.m.*	*Tons*
9:00-9:06 . .	1/10	6.5	7,000	0.5
9:06-9:12 . .	1/10	39	28,000	12.3
9:12-9:18 .	1/10	74	43,000	37.1
9:18-9:30 . .	1/5	84	51,200	100.3
9:30-9:36 . .	1/10	79	51,700	47.7
9:36-9:42 . .	1/10	56	49,000	32.0
9:42-9:48 . .	1/10	34	41,500	16.5
9:48-10:00 .	1/5	13	27,000	7.9
10:00-10:12 .	1/5	4.7	14,400	1.5
10:12-10:42 .	1/2	1.7	6,000	.5
Total . . .	—	[1]50.04	—	256.3

[1] In c.f.s. = hours.

Exhibit 76. Summary of Rainfall, Streamflow, and Sediment Discharge, Both Total and Peak Intensity, for Storm of August 4, 1960$^{(A-19)}$

Storm items	Total	Peak rates for maximum 12-minute period
Rainfall	1.82 inches from 9 to 11:20 p.m. 1.68 inches from 9 to 9:33 p.m.	Estimated 4 inches per hour.
Streamflow. .	2.1 c.f.s.-days 0.87 inch.	84 c.f.s. (from 58 acres) 927 c.f.s. per sq. mi. 1.44 inches per hour. 51,200 parts per million.
Sediment . . .	260 tons.	8.4 tons per minute for 58 acres. 12,000 tons per day for 58 acres. 132,000 tons per day per sq. mi.

Exhibit 77. HYDROLOGIC AND SEDIMENTOLOGIC DATA BY STORM EVENTS FROM A DRAINAGE AREA AFFECTED BY RESIDENTIAL CONSTRUCTION(A-19)

Date	Precipitation (R_q)	Water discharge (Q_w)		Sediment		Peak flow (P_n)	Mean air temperature (T_a)
		C.f.s.-days	Inches	Discharge (Q_s)	Concentration (C)		
1959	*Inches*			*Tons*	*P.p.m.*	*C.f.s.*	°*F.*
July 1	1.7	0.81	0,332	128	59,200	25	74
Oct. 1	.9	.39	.160	60	54,500	9.0	61
Nov. 7	.8	.25	.103	14.7	21,800	1.8	48
Dec. 28	.44	.048	.020	5.0	37,200	2.0	35
1960							
Jan. 3	.8	.156	.064	14.3	32,800	5.0	33
Feb. 18	.7	.59	.242	73	46,700	11.1	34
Apr. 3	.4	.194	.080	20.3	38,700	1.6	49
May 8	1.5	.76	.312	55	26,800	6.0	61
May 21	.6	.23	.094	37	57,300	12	64
May 22	.6	.39	.160	72	65,300	15	64
July 11	.7	.158	.064	11.7	27,400	5.0	75
July 30	1.0	.53	.218	20.2	14,000	3.1	75
Aug. 3	.8	.52	.213	48	34,000	13	74
Aug. 4	1.8	2.08	.854	256	44,000	84	74
Sept. 12	4.1	2.68	1.102	123	17,000	20	68
1961							
Mar. 8	.4	.233	.096	6.0	9,600	7.8	41
May 7	.6	.149	.061	11.7	29,000	13.5	61
May 12	.3	.37	.152	12.6	12,700	9.0	61
June 9	.22	.032	.013	.7	7,700	2.1	69
June 14	1.0	.48	.197	18.9	14,600	22	70
July 24	.30	.042	.017	.8	6,900	3.3	75
Aug. 9	.6	.21	.086	4.1	7,350	12.9	74
Sept. 3	.30	.125	.051	1.4	4,200	12.3	70
Oct. 21	.5	.45	.185	4.4	3,550	3.4	54
1962							
Jan. 6	.6	.23	.094	.9	1,490	3.9	33

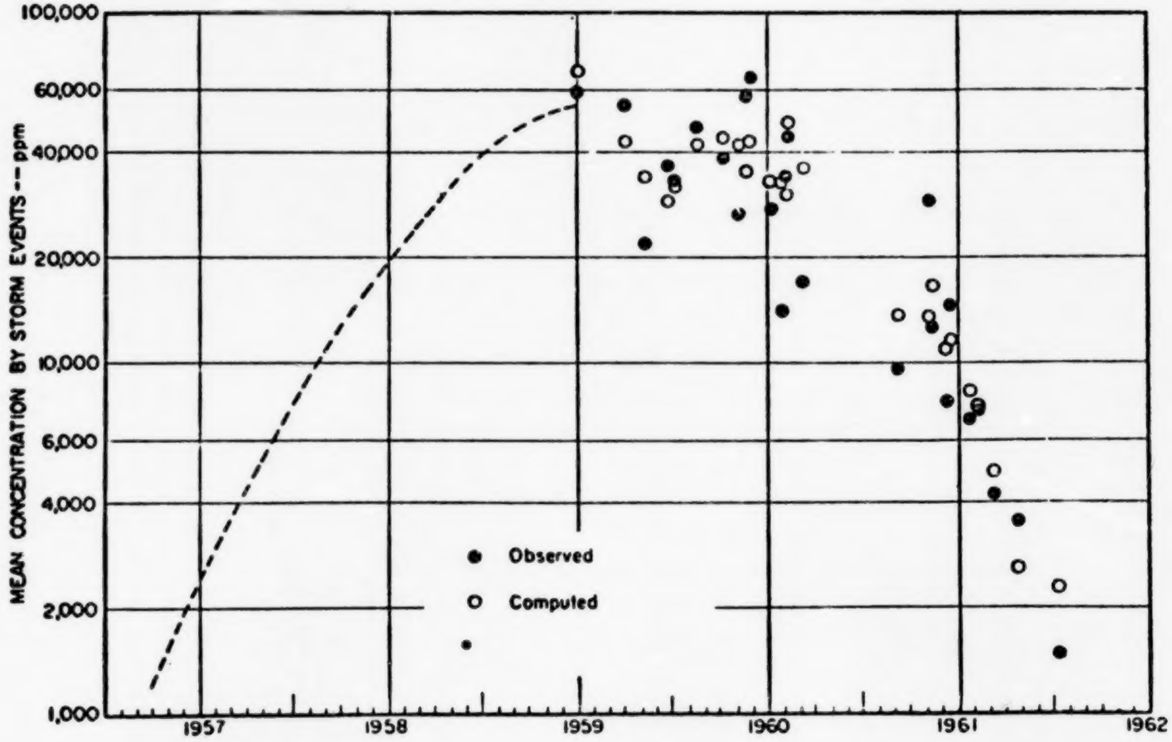


Exhibit 78. Variation of Mean Sediment Concentration of Storm Runoff from an Area of Residential Construction at Kensington, MD , 1957-62.(A-19)

(The Line to July 1959 is Estimated on Basis of Visual Observations of Construction Areas and the Drainage Channels.)

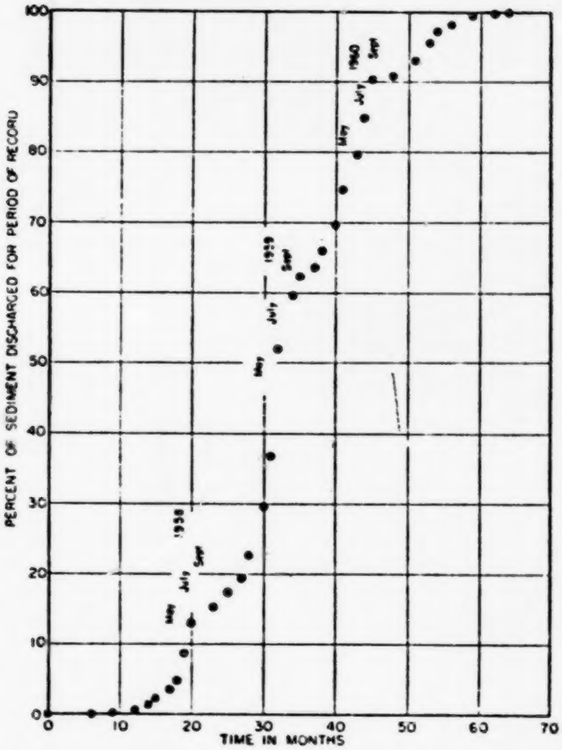


Exhibit 79. Cumulative Sediment Discharged from the Construction Area With Time.(A-19)
(Note the Higher Rates of Yield During Summer Months.)

Considering that the study period covered about 2.5 years, this result is equal to 75 tons/acre/year. Sediment yield from the previously-developed portions of the watershed was estimated to be 0.75 tons/acre/year.

The sediment yield from the construction area of the Kensington watershed was 121,000 tons/square mile total, or about 48,000 tons/square mile/year for a 2.5 year period. This rate is compared to the rate of sediment accumulation at Lake Barcroft in Fairfax, Virginia (also a suburb of Washington, D.C.), which averaged 1,300 tons/square mile/year of urbanized area, over an urbanized area of 9.5 square miles and over a period of about 19 years. One reason postulated for this difference is the building method. The homes in the Virginia suburb were custom built, exposing a relatively small area of soil at each home site, while in the Maryland suburb the building method involved exposing a much larger area (a 3 to 10-acre subarea) during the construction period.

Case 10. Effects of Construction on Fluvial Sediment, Urban and Suburban Areas of Maryland

Source -

Wolman, M. G. and Schick, A. P., "Effects of Construction on Fluvial Sediment, Urban and Suburban Areas of Maryland," Water Resources Research, Vol. 3, No. 2, 1967.(A-56)

Purpose -

This study was undertaken to determine the amounts of sediment being contributed to Maryland streams and the effects of that sediment; and to search for courses of action to combat the problems of erosion and sedimentation.

Site Location/Description -

Study sites were in metropolitan Baltimore and part of metropolitan Washington, D.C., lying in the state of Maryland. Population: about 2,000,000 inhabitants in each metropolitan area.

Topography -

Average slopes in this area range from 1 to 10 percent with some places 20 percent or more.

Soil Type -

Very deep soils prevail in this area with outcrops of bedrocks in only very few locations.

Climate/Rainfall -

Annual rainfall is 42 inches. During the summer, 2-iph intensity rainfalls occur with a frequency of 10 years. Snowfall and snowcover during the winter months remain generally less than two weeks.

Study Method -

Sediment yield figures in tons/mi^2/yr were compiled for 12 different construction sites in Washington, D.C. and Maryland.

Results -

Sediment Yield from Construction Areas:

The sediment yields from areas undergoing construction ranges from 1000 to 100,000 tons per square mile per year depending upon the size of the drainage area. Exhibit 80 presents the sediment yield from some selected drainage basins undergoing development. For comparison, Exhibit 81 gives the sediment yield from rural drainage areas in the same study areas, and depicts the relationship between sediment yield, drainage area, and construction activity.

Sediment Concentration:

Suspended sediment concentration from areas undergoing construction ranged from 3,000 to 150,000 ppm; in natural and agricultural catchment areas, the value was about 2,000 ppm.

Duration and Amount of Land Exposed during Construction:

The study showed that about 50 percent of sites were open for eight months, 60 percent for nine and 25 percent more than one year. The total land area exposed to construction remained almost constant throughout the year. Average size of construction site for one building was 14,400 square feet. The total area cleared for construction in all the four counties in Maryland between Baltimore and Washington, D.C., was about 7.2 square miles (housing and other buildings: 5.7 square miles, for highways: 1.5 square miles).

Exhibit 80. SEDIMENT YIELD FROM SELECTED DRAINAGE BASINS: MARYLAND AND OTHER AREAS$^{(A-56)}$

Reference Number	Stream and Location	Drainage Area, sq mi.	Sediment Yield tons/mi^2/yr	Condition
1	Johns Hopkins University Baltimore, Md.	0.0025	140,000	construction site Construction covered entire drain area
2	Tributary, Minebank Run Towson, Md.	0.031	80,000	commercial
3	Tributary, Kensington, Md.	0.091	24,000	housing subdivision [Guy, 1963]
4	Tributary, Gwynns Falls, Md.	0.094	11,300	housing (yield computed from small stilling basin, probably low trap efficiency)
5	Oregon Branch, Cockeysville, Md.	0.236	72,000	industrial park
6	Cane Branch, near Somerset, Ky.	0.67	1,147	strip mine [Collier et al., 1962]
7	Greenbelt Reservoir, Greenbelt, Md.	0.83	5,600	housing [Guy and Feguson, 1962]
8	Little Falls Branch, Bethesda, Md.	4.1	2,320	urban and development (includes urban area as well as area undergoing development. Wark and Keller [1963]
9	Lake Barcroft, near Fairfax, Va.	9.5	32,500	housing subdivision (for maximum year, Holeman and Geiger [1959]
10	Northwest Branch Anacostia River near Hyattsville, Md.	49.4	1,850	urban and development (includes urban area as well as area undergoing development. [Wark and Keller, 1963; Keller, 1962]
11	Rock Creek, Sherrill Dr. Washington, D.C.	62.2	1,600	urban and development (includes urban area as well as area undergoing development). [Wark and Keller, 1963; Keller, 1962]
12	Northeast Branch Anacostia near Riverdale, Md.	72.8	1,060	urban and development (includes urban area as well as area undergoing development). [Wark and Keller, 1963; Keller, 1962]

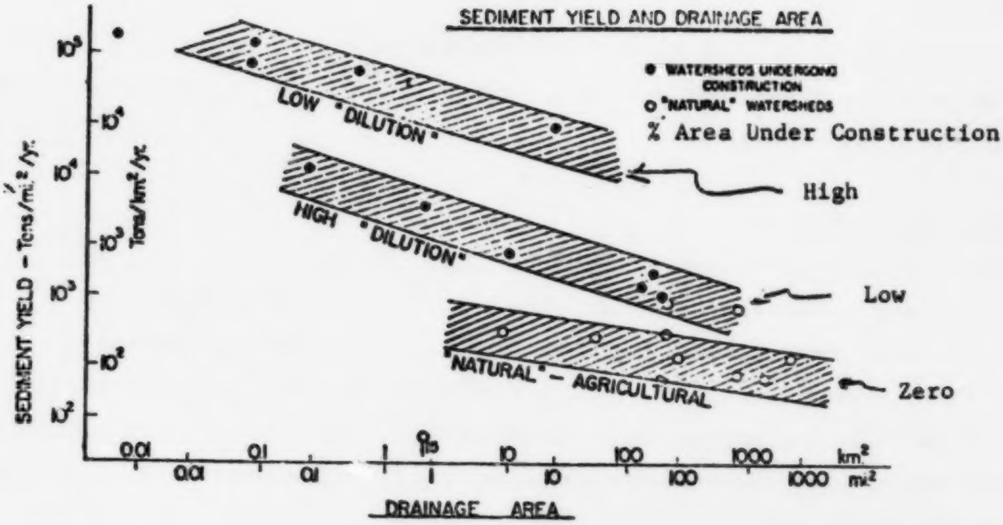


Exhibit 81. Sediment Yield, Drainage Area, and Construction Activity (A-56)

Case 11. Some Sediment Aspects of Tropical Storm Agnes

Source -

H. P. Guy and I. L. Clayton, "Some Sediment Aspects of Tropical Storm Agnes," Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol. 99, No. HY9, Technical Notes, Proc. Paper 10024, Sept. 1973, pg. 1653.(A-20)

Purpose -

The purpose of this study was to document the effects of Tropical Storm Agnes on the runoff and sediment loading from a small watershed exposed by construction activities.

Site Description -

The watershed of interest is that of Stave Run at Reston, Va., 20 miles west of Washington, D.C. The basin area is 49.1 acres. Of this, 13.7 acres contain hardwood forests; 8.6 acres are covered by asphalt paving; and 2.7 acres are covered by the main building for the new U.S. Geological Survey Headquarters. The remaining 24.1 acres are exposed for construction purposes, including storage areas; vehicle access roads; and a 1.6 acre pile of stockpiled topsoil. Much of the drainage from this construction area is through storm sewers, with hay bales placed in front of inlets from potential erosion areas.

Time Frame -

The storm and measurements took place in the three-day interval June 21 through June 23, 1972.

Precipitation -

The total daily precipitations during the storm were: June 20 -- .49 inches; June 21 -- 10.29 inches; June 22 -- 2.34 inches; June 23 -- .81 inches, a total of 13.44 inches over the last three days. Exhibit 82

Exhibit 82. RAINFALL INTENSITIES AND RECURRENCE INTERVALS FOR DIFFERENT TIME INTERVALS, JUNE 21, 1972[(A-20)]

STAVE RUN, VA.

Period (1)	Beginning time, in hours (2)	Rainfall amount, in inches (3)	Intensity in inches per hour (4)	Recurrence interval, in years (5)
16 hr.	1440	11.15	0.70	>100
8 hr.	1630	9.14	1.14	>100
4 hr.	1855	5.76	1.44	>100
2 hr.	1855	3.41	1.70	20
1 hr.	1912	1.90	1.90	3
30 min.	1855	1.30	2.60	1.6
15 min.	1912	0.75	3.00	<1
10 min.	1912	0.57	3.43	<1
5 min.	1914	0.33	3.90	<1

shows the maximum rainfall intensities and gives their recurrence intervals for various time periods during the storm. Exhibit 83 compares this data with the 50-year intensity-duration curve for Washington, D.C. In general this was a high intensity, long duration storm, although it was comparatively low in intensity for shorter intervals during the storm.

Study Method -

Runoff was measured as it passed through a flume into the stream. Samples were taken at the flume and analyzed for sediment concentration and particle size. These data were taken continuously throughout the storm.

Results -

A trapezoidal flume was constructed at the north end of the construction area. Mean flow for the storm was: June 21 -- 11.6 cfs; June 22 -- 3.66 cfs; and June 23 -- 1.73 cfs. The 3-day total runoff was 8.24 inches, or 61 percent of the total rainfall for the 49.1 acre basin. Exhibit 84 shows the cumulative rainfall and runoff.

Sediment yield was determined by taking samples from the flue. These samples were verified by integration of hand sampling. The average concentrations were determined and multiplied by the average discharge to determine the total sediment discharge. These figures came to 459 tons on June 21; 25.9 tons on June 22; and 7.4 tons on June 23. The sediment concentration was 14,700 mg/l on June 21. Over the three-day period, a total of 492 tons was transported past the flume, an average yield of 20.4 tons/acre, assuming negligible yields from woods, paved area and building structure. During the half-hour peak flow, sediment yield came to 102 tons, equivalent to 8.5 tons/acre/hour.

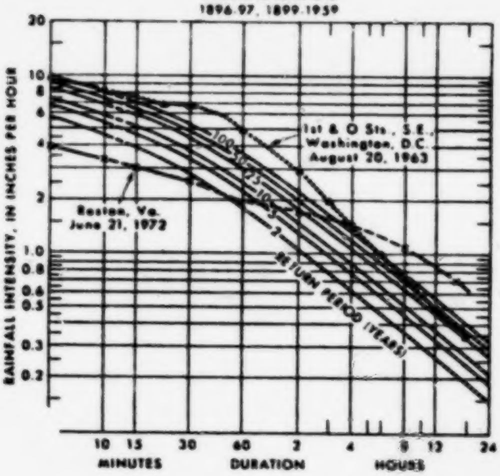


Exhibit 83. Rainfall Intensity-Duration-Frequency Curves
At Washington, D.C., Showing Maximum Intensities on August 20, 1963,
in Washington, D.C., and on June 21, 1972 in
Reston, Va. (Return Period Graphs from USWB Tech. Paper 25, 1955)$^{(A-20)}$

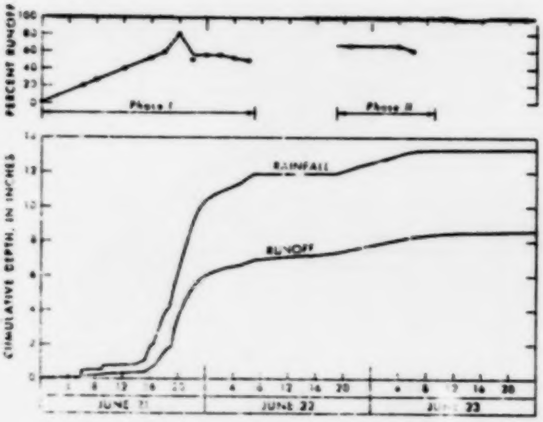


Exhibit 84. Cumulative Rainfall and Runoff June 21-23, 1972, With Instantaneous Relative Runoff, as Percentage(A-20)

STAVE RUN, VA.

Particle size analysis is reported in Exhibit 85. Distributions of various samples ranged from 2-10 percent sand, 36-60 percent silt and 30-59 percent clay, averaging 6 percent gravel, 25 percent sand, 46 percent silt and 23 percent clay. Much of the eroded sediment was site deposited at the bases of steep slopes and in depressions in the construction area.

This study points out the effects that a large storm can have on an exposed area. In three days, water moved 961 tons of sediment, carrying 492 tons completely off the 24-acre site.

Exhibit 85. SEDIMENT ERODED, SITE DEPOSITED, AND TRANSPORTED BY STAVE RUN PAST GAGING SITE, IN TONS (A-20)

Process (1)	Gravel (2)	Sand (3)	Silt (4)	Clay (5)	Total (6)
Eroded and exposed	58	240	442	221	961
Site deposited	58	210	201	0	469
Transported	0	30	241	221	492

Case 12. Prediction of Subsoil Erodibility Using Chemical, Mineralogical, and Physical Parameters

Source -

Roth, C. B., Nelson, D. W., Romkens, M. J. M., Prediction of Subsoil Erodibility Using Chemical, Mineralogical and Physical Parameters, National Environmental Research Center, Cincinnati, Ohio, December 1973.(A-43)

Purpose -

The purpose of this study was to test the soil erodibility model on soils characterized by textural extremes such as the subsoils at construction sites. A second task was to determine various characteristics which were peculiar to these subsoils and to improve the soil erodibility model so that these soils would be included, or to develop a new, separate model for the subsoils.

In 1971, W. H. Wischmeir presented a simple method of determining the K factor (erodibility factor) of soils through the use of a nomograph. It was found in the present study that this nomograph could not be improved upon in estimating the K factor for surface soils. However, the nomograph was found to be inadequate in determining the K factor of subsoils.

Soil Type -

Six subsoils were selected from a wide geographical area in the middle west; these soils, chosen primarily for their clay content, were: McGary silty clay near Bloomington, Monroe County, Indiana; Portageville clay near Portageville, New Madrid County, Missouri; St. Clair silty clay near Woodburn, Allen County, Indiana; Wymore silty clay near Burr, Otoe County, Nebraska; Pawnee clay loam near

Burr, Otoe County, Nebraska; Mayberry clay loam near Burr, Otoe County, Nebraska. The clay content for each of these was: McGary 39.8 percent; Portageville 66.5 percent; St. Clair 38.7 percent; Wymore 38.5 percent; Pawnee 35.4 percent; and Mayberry 33.9 percent.

Topography -

Top soil was removed and each site area was sloped to 9 percent steepness.

Study Method -

Simulated rainstorms were applied to each study plot with a rainulator. Soil loss and runoff were computed by integrating the measured hydrograph and the acquired sediment content values of collected runoff samples. For each soil type and treatment, three simulated storms were administered in durations of 60 minutes, 30 minutes, and 30 minutes. Slope ranged from 8.7 percent to 9.1 percent but was generally 9.0 percent. For the combination of 3 storms, the adjusted soil loss for each soil type was:

McGary	Scalped	95.10 t/ha
	Semi Compacted Fill	90.48 t/ha
	Tilled	52.32 t/ha
Portageville	Scalped	12.93 t/ha
	Semi Compacted Fill	13.92 t/ha
	Tilled	3.31 t/ha
St. Clair	Scalped	127.92 t/ha
	Semi Compacted Fill	106.92 t/ha
	Tilled	81.24 t/ha
Wymore	Scalped	126.99 t/ha
	Tilled	16.09 t/ha

Pawnee Scalped	125.60 t/ha
Tilled	77.43 t/ha
Mayberry Scalped	174.41 t/ha
Tilled	11.99 t/ha

An observed K factor for each subsoil was computed using observed soil loss measurements for each storm and treatment, which were adjusted to the standard conditions of 9 percent slope and 72.6-ft slope length. The K factors are computed as the average soil loss per unit R, where R represents the number of erosion-index units for a given storm as defined in the Universal Soil Loss Equation. Figures were also adjusted to be annual in basis, and an adjustment was also made to account for the simulated nature of the storms. The observed K factors (K_{obs}) were then compared to the K factors for the subsoils (tilled and scalped) which were derived using the Wischmeir nomograph. The results are presented in Exhibit 86 and Exhibit 87. It can be readily seen that the nomograph is not very effective in determining the K factor of subsoils. Its effectiveness in computing K factor of surface soils, however, is demonstrated in Exhibit 88.

A nomograph was generated for estimating the K factor of high clay soils through laboratory characterization of the soils in this study in terms of physical, chemical, and mineralogical properties; and by applying these characterizations to a statistical regression analysis.

Parameters Measured -

Physical:

Particle size distribution, sand fractions, new silt, new sand, M (see page 250), structure, permeability.

Chemical:

Citrate-dithinite extractable total P, total N, total C, pyrophosphate extractable carbon, hot H_2O extractable carbon, periodate consumed.

Exhibit 86. OBSERVED AND PREDICTED (PER WISCHMEIER) SOIL ERODIBLITY FACTORS FOR TILLED SUBSOILS$^{(A-43)}$

Soil	Soil ID number	Kobs	Total[a] organic carbon %	Organic[a] matter %	Sand[b] (100), %	Silt[b] (2-100), %	Struc-[c] ture	Perme-[c] ability	Knomo[d]
McGary	191E	0.17	0.34	0.54	0.46	59.05	4	6	0.43
Portageville	192E	0.01	1.23	2.12	0.00	32.15	4	6	0.21
St. Clair	212E	0.31	0.75	1.29	9.80	48.82	4	6	0.34
Wymore	210E	0.03	0.92	1.58	2.01	53.45	4	6	0.34
Pawnee	206E	0.24	0.82	1.41	20.56	38.68	4	6	0.29
Mayberry	208E	0.04	0.82	1.41	7.56	54.18	4	6	0.37

[a] Determination according to Mebius (1960). Conversion factor for organic carbon to organic matter was taken to be 1.72.

[b] Procedures described in section V.

[c] Evaluations were made from soil profile descriptions.

[d] Soil erodibility factor, K, as determined from the nomograph of Wischmeier et al., 1971.

Exhibit 87. OBSERVED AND PREDICTED (PER WISCHMEIER) SOIL ERODIBILITY FACTORS FOR SCALPED SUBSOILS(A-43)

Soil	Soil ID number	Kobs	Total[a] organic carbon %	Organic[a] matter %	Sand[b] (100), %	Silt[b] (2-100), %	Struc-[c] ture	Perme-[c] ability	Knomo[d]
McGary	191S	0.36	0.34	0.58	0.46	59.05	4	6	0.43
Portageville	192S	0.05	1.23	2.12	0.00	32.15	4	6	0.21
St. Clair	212S	0.48	0.75	1.29	9.80	48.82	4	6	0.34
Wymore	210S	0.49	0.92	1.58	2.01	53.45	4	6	0.34
Pawnee	206S	0.45	0.82	1.41	20.56	38.68	4	6	0.29
Mayberry	208S	0.67	0.82	1.41	7.56	54.18	4	6	0.37

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[a] Determinations according to Mebius (1960). Conversion factor for organic carbon to organic matter was taken to be 1.72.

[b] Procedures described in section V.

[c] Evaluations were made from soil profile descriptions.

[d] **Soil erodibility factor, K, as determined from the nomograph of Wischmeier et al., 1971.**

Exhibit 88. OBSERVED AND PREDICTED (PER WISCHMEIER) SOIL ERODIBILITY FACTORS FOR SURFACE SOILS(A-43)

Soil name	Sample ID number	Soil erodibility factor[a]	
		Knomo	Kobs
Bedford	101	.46	.46
	103	.39	.39
Bewleyville	104	.36	.39
Cincinnati	105	.52	.54
Muren	106	.42	.43
Russell	112	.44	.42
Rossmoyne	114	.51	.55
Switzerland	115	.41	.40
	117	.47	.51
	119	.45	.43
Parr	121	.30	.33
Morley	123	.30	.26
Miami	125	.26	.22
Miami	126	.24	.25
Fox	128	.28	.28
	131	.24	.25
	133	.41	.42
Princeton	135	.08	.07
Princeton	140	.50	.39
Princeton	144	.08	.07
Pembroke	145	.53	.54
Morley	147	.31	.25
Elkinsville	149	.41	.42
Varna	150	.29	.27
Frederick	152	.43	.39
Morley	154	.38	.37
Russell	155	.44	.48
Ockley	157	.39	.41
Grayford	160	.51	.58
Miami	162	.32	.36
Warsaw	164	.13	.11
Zanesville	166	.52	.52
Marlove	168	.34	.36
Markland	169	.22	.20
Zanesville	170	.40	.36
Celina	171	.26	.24
Celina	172	.38	.34
Morley	174	.48	.47
Wea	176	.24	.26
Parr	178	.24	.25
Foxgrav	179	.09	.09
Morley	180	.37	.38
Avonburg	182	.54	.55
Pawnee Topsoil	207	.28	.37
Mayberry Topsoil	209	.31	.31
Wymore Topsoil	211	.32	.34

[a] Knomo is the K factor derived from the soil erodibility nomograph developed by Wischmeier et al.(1971) and Kobs is the K factor actually measured.

Mineralogical (Clay mineralogical composition of soils):

Percent of the clay fraction of vermiculite, mica, kaolinite plus halloysite, amorphous material, montmorillonite, quartz plus feldspar, chlorite.

Time Frame -

Site preparation for field tests started August 16, 1971; tests were run in September and October 1971 and again the following summer in August and September. Laboratory tests immediately followed field tests.

Results -

The nomograph shown in Exhibit 89 was derived for use in estimating the K factor of high clay subsoils.

The equation used to derive this nomograph is:

$$\text{Kpred} = 0.32114 + 20.167 \times 10^{-5}\ M - 0.14440\ (\%Fe_2O_3 + \%\ Al_2O_3) - 0.83686\ (\%\ SiO_2)$$

where M = (% new silt + % new sand) % new silt)

Exhibit 90 shows a comparison of observed and derived K factors using this new nomograph of subsoils.

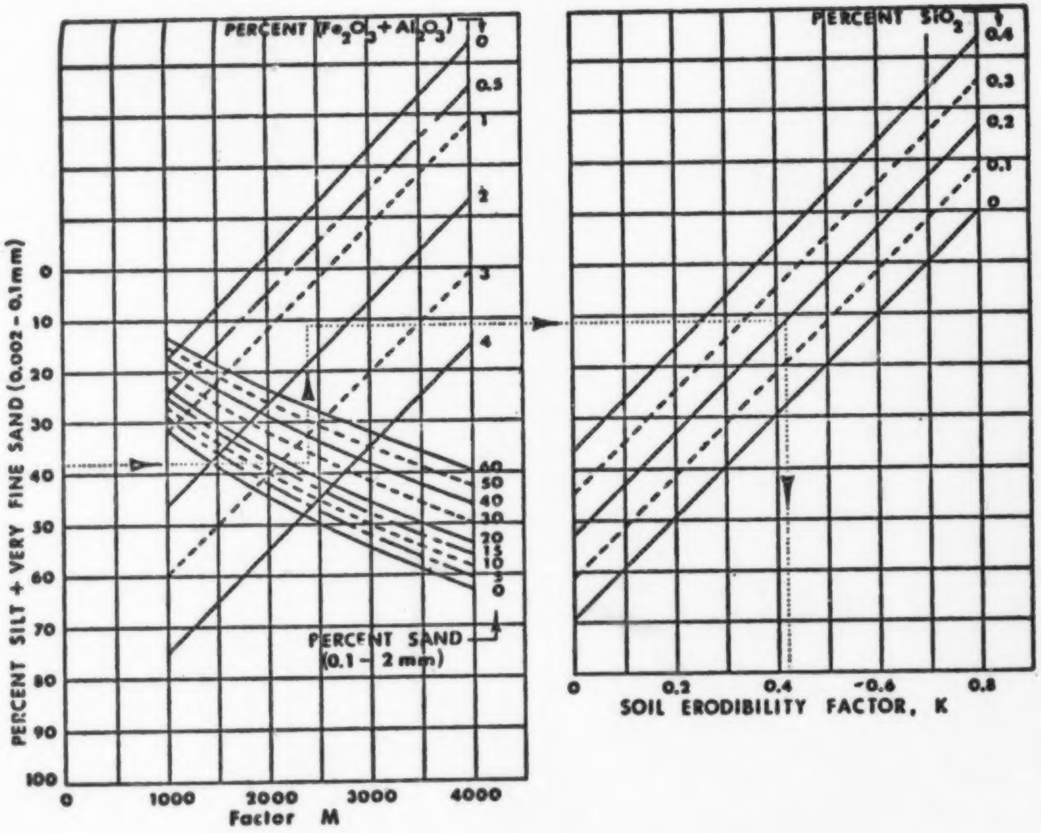


Exhibit 89. Nomograph for Predicting the Erodibility Factor K of High Clay Subsoils(A-43)

EXHIBIT 90

COMPARISON OF THE SOIL ERODIBILITY FACTOR, K, DETERMINED IN FIELD EXPERIMENTS AND THOSE COMPUTED FROM THE SUBSOIL NOMOGRAPH (A-43)

Soil	Sample ID number	Soil erodibility factor, K Observed	 Nomograph [a]
Dayton	188	.54	.57
McGary	191S	.36	.39
Portageville	192S	.05	.08
St. Clair	212S	.48	.39
Pawnee	206S	.45	.42
Mayberry	208S	.67	.69
Wymore	210S	.49	.49

[a] Soil erodibility factor, K, as determined from Exhibit 89.

The investigators believe that this nomograph can be used with a fair degree of confidence in soils similar to those in the study. However, its use with soils with large concentrations of iron and aluminum should be avoided, as this nomograph would tend to underestimate K factor in these cases. More investigation is also needed in subsoils with varying structures and permeabilities.

Case 13. Soil Erosion in the Detroit Metropolitan Area.

Source -

Thompson, J. R., "Soil Erosion in the Detroit Metropolitan Area," Journal of Soil and Water Conservation, Vol. 25, No. 1, Jan.-Feb., 1970. (A-49)

Purpose -

This study was undertaken in order to place quantitative values on the rates and amounts of erosion from urban construction sites in the Detroit area.

Site Location/Description -

It is estimated that 80 percent of the population of the Great Lakes Basin is concentrated in 18 metropolitan complexes which cover only a small part of the land. In 1960, there were approximately 1.2 million housing units in the Detroit and Ann Arbor areas alone and 30 percent of these units were built between 1950 and 1960. Population is expected to grow 225 percent above the 1960 level by the year 2020.

Topography -

The Southeast Michigan Rivers Survey area is about one-half rolling glacial drift plains and one-half Huron-Erie lake plains. The area ranges from level to gently rolling on the lake plains to rolling to steep on the glacial drift.

Soil Type -

The lake plains are comprised largely of poorly drained silts and clays with some sandy soils on broad low ridges. The glacial drift plains are comprised mainly of sandy soils; large areas of productive clay and mixed sand and clay soils; and deep soils in level, low-lying pockets.

Study Method -

A total of 760 plots was chosen from the Conservation Needs Inventory plots (380 plots, generally about 160 acres) and from random methods (380 quarter-section samples). Data concerning soil type, slope, erosion, land use, and conservation treatment needs were compiled for each plot and inventoried by computer. This represented a 4 percent sample. An arbitrary delineation was made of the Detroit metropolitan area comprising 33 townships in Oakland, Macomb, Wayne, and Washtenaw Counties and excluding the city of Detroit. This zone is where the bulk of the urbanization is taking place. This delineation also establishes a zone in which a systematic statistical sampling procedure can be used. The sample was increased to 7 percent in this high urbanization zone (See Exhibit 91). In addition to the other information that was compiled for all of the other plots, current information on construction activity was also compiled for these highly urbanized plots.

The Universal Soil Loss Equation was used to compute soil loss for rural plots. Data on soil type, slope, erosion, land use, and conservation needs were obtained by field observation for the sample plots. Soil loss in the urban areas was computed using the soil loss curve developed by Schmidt and Summers[(A-46a)] (See Exhibit 92). Acreage of land disturbed by construction is shown in Exhibit 93. Drainage subareas were derived from drainage or watershed boundaries and were ascribed mean annual erosion rates which were computed as the arithmetic average of the sample plots lying within the subarea (See Exhibit 94).

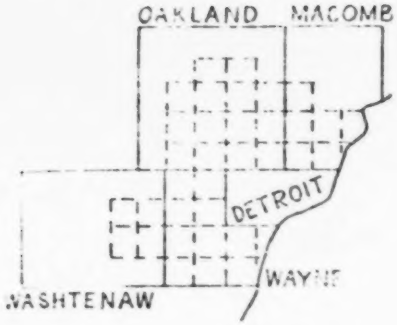
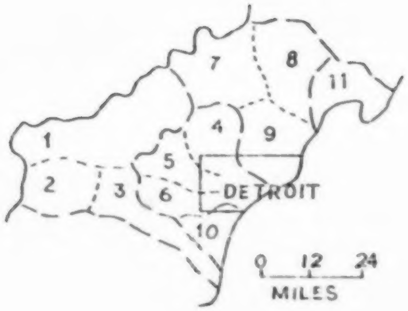

OAKLAND
MACOMB
DETROIT
WAYNE
WASHTENAW

Exhibit 91a. Detroit Metropolitan Area Erosion Study: Townships$^{(A-49)}$


1
2
3
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DETROIT
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24
MILES

Exhibit 91b. Subareas (See Table 80 for Average Annual Erosion Rates by Subarea)$^{(A-49)}$

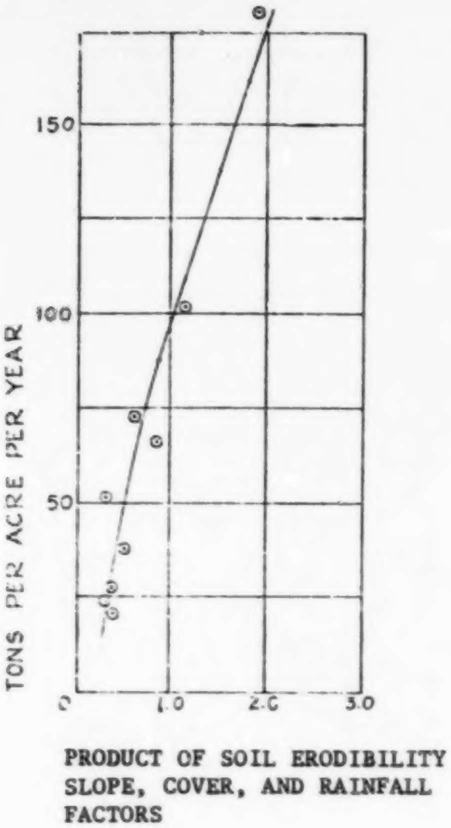

Exhibit 92. Curve for Determining Erosion Rates, After Schmidt and Summers(A-49)

Exhibit 93. LAND DISTURBED BY BUILDING AND CONSTRUCTION ACTIVITY, SUMMER 1968[(A-49)]

County	Townships	Sample Plots	Sample Totals		Acres-Entire Urban Zone
			Acres	% of Area	
Macomb	5	45	123.5	1.7	1,981
Oakland	14	140	484.0	2.2	6,967
Washtenaw	4	40	126.5	2.0	1,815
Wayne	10	100	360.5	2.3	5,184
Total	33	325	1,094.5	2.1[a]	15,947

[a] Weighted average.

Exhibit 94. EROSION RATES IN SUBAREAS NEAR THE DETROIT METROPOLITAN AREA (A-49)

Subarea	Number of Sample Plots	Erosion (tons/acre/year) Mean	Erosion (tons/acre/year) Range
Huron River			
Upper (1)[a]	83	2.8	0 - 23.8
Mill Creek(2)	27	4.9	0.3 - 10.7
Lower(3)	47	2.7	0.2 - 13.2
Total	157	3.0	0 - 23.8
Rouge River			
Upper (4)	50	0.6	0.1 - 10.9
Middle(5)	27	1.9	0.2 - 10.1
Lower(6)	20	2.3	0.1 - 8.2
Total	97	1.3	0.1 - 10.9
Clinton River			
Upper(7)	70	1.9	0 - 13.8
North(8)	42	2.1	0.1 - 18.0
Lower(9)	53	0.5	0.2 - 3.4
Total	165	1.5	0 - 18.0
South Detroit Tributaries(10)	24	1.4	0.1 - 4.4
North Lake St. Clair Tributaries(11)	19	1.5	0.1 - 5.2

[a] Numbers in parentheses indicate location of subarea

Results -

The erosion rates of the established urban sector, which are already developed, are usually significantly below the erosion rates attributed to agricultural areas with similar soils and topography. However, while these rates are usually lower than the rates for agricultural land, these lower rates are overshadowed by the high rates of erosion generated by construction activity. Exhibits 94, 95, and 96 present the erosion data that support these conclusions.

Exhibit 95. **TONS OF EROSION FROM BUILDING AND CONSTRUCTION ACTIVITY, SUMMER 1968(A-49)**

County	Tons	Average Tons/Acre/Year
Macomb	80,813	42
Oakland	519,041	75
Washtenaw	152,147	84
Wayne	359,251	69
Total	1,111,252	69[a]

[a] Weighted average.

Exhibit 96. AVERAGE ANNUAL EROSION RATES FROM CONSTRUCTION AND NON-CONSTRUCTION SOURCES, SUMMER 1968(A-49)

County	Sample Plots	Tons/Acre/Year		Total
		Construction Sources	Non-construction Sources	
Macomb	45	0.7	0.6	1.3
Oakland	140	1.6	1.5	3.1
Washtenaw	40	1.7	3.3	4.9
Wayne	100	1.6	1.3	2.9
Total	325	1.5[a]	1.5[a]	3.0[a]

[a] Weighted averages.

Case 14. Rock Creek-Anacostia River Basins

Source -

T. H. Yorke and W. J. Davis, "Sediment Yields of Urban Construction Sources, Montgomery County, Md.," United States Department of the Interior Geological Survey, Open-file Report, Rockville, Maryland, 1972.(A-57)

Purpose -

"To evaluate some features of the sediment control as practiced in the County (Montgomery) and to provide information for improving erosion-control techniques." This report covers only the first phase of the study which measured the sediment yields due to essentially uncontrolled construction activities. The second phase (unreported) is to measure and evaluate the various sediment control programs in the basin.

Site Description -

The watersheds under study were those of the upper Rock Creek and Anacostia Rivers, an area of 34 square miles. These basins are in eastern Maryland, about 7 miles north of the District of Columbia. This area lies in the eastern Piedmont physiographic province, typified by rolling topography. Slopes range between 0 and 8 percent along drainage divides and up to 25 percent adjacent to the streams. The bedrock is comprised of Precambrian igneous and meta-igneous rocks of variable erodibility (See Exhibit 97).

Climate -

This area has a typical mid-Atlantic temperate, moderately humid climate. Mean annual temperature is 13°C. The growing season is 175 days, between late April and mid-October. Average annual precipitation is 43 inches, distributed evenly over the year. Average

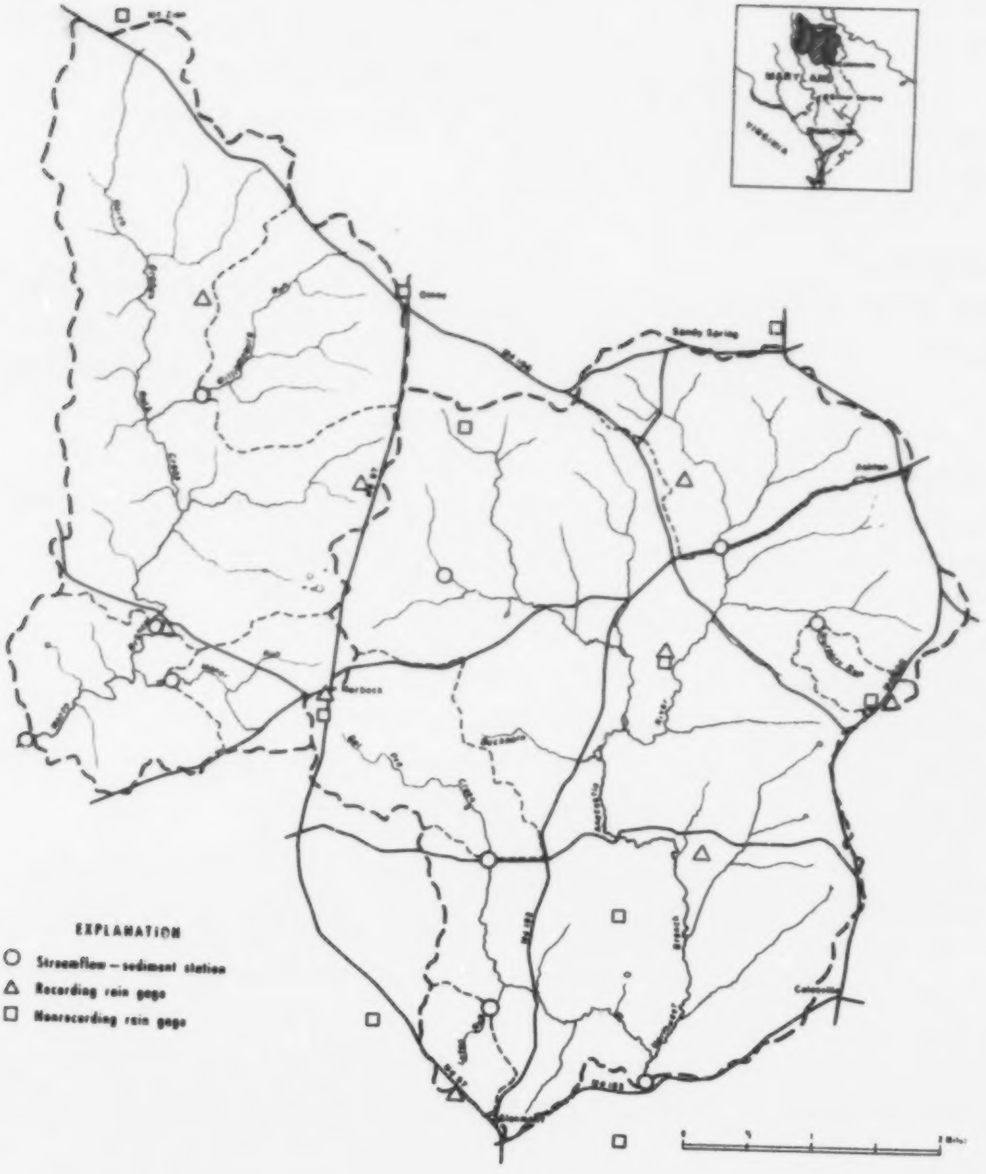
EXPLANATION
○ Streamflow — sediment station
△ Recording rain gage
□ Nonrecording rain gage
MARYLAND
VIRGINIA
Sandy Spring
Olney
Norbeck
Ashton
Colesville

Exhibit 97. Map of Study Area, Rock Creek-Anacostia River Sedimentation and Hydrology Project, Maryland(A-57)

monthly precipitation ranges between 2.7 inches in February to 5.15 inches in August. Summer precipitation tends to occur as brief high-intensity storms. Actual precipitation during the study averaged 41.3 inches/year. Average runoff from the Northwest Branch of the Anacostia River near Colesville was 17.7 cfs compared to the 45 year average of 20.2 cfs.

Soil Type -

The predominant Manor-Chester-Glendes soil is primarily derived from a soft micaceouschist. The soils range from 18-40 inches deep with a 0-8 inch silty loam surface soil. The surface soil size distribution is 0-30 percent clay, 0-30 percent sand, and 50-90 percent silt. Permeability ranges .63 to 2.0 inches per hour. These soils are highly susceptible to erosion and in places the surface soil has been eroded away, exposing the subsoils.

Land Use -

The area studied is essentially rural but is shifting rapidly to urban; see Exhibits 98 and 99. This is especially apparent in the lower third of the area; however, subdivisions and commercial developments are being built throughout the basin.

Study Method -

Land use changes were determined from grid counts on aerial photographs. Streamflow and sediment concentration data were measured at nine sites shown in Exhibit 98. Streamflow was based on the water level at each station, calibrated to discharge measurements. Precipitation data were collected at approximately 15 stations shown on Exhibit 97.

Results -

Exhibit 100(a-g) contain the streamflow and sediment load data for the well-sampled storm periods. The storm runoff was determined

Exhibit 98. LAND USE IN PERCENT OF DRAINAGE AREA, IN SELECTED BASINS IN MONTGOMERY COUNTY, MARYLAND, 1959-68(A-57)

Date	Cultivated	Grass	Woodland	Urban	Construction
Bel Pre Creek at Layhill					
Nov. 1959	12.4	28.5	57.5	1.6	0
Mar. 1963	12.4	28.5	57.5	1.6	0
Dec. 1964	.6	38.0	56.7	1.6	3.1
July 1965	0	33.6	46.8	1.6	18.0
June 1966	.9	41.4	38.5	5.2	14.0
June 1967	.8	40.4	36.4	8.5	13.9
June 1968	.8	43.3	36.1	9.9	9.8
Lutes Run at Lutes					
Nov. 1959	0	26.0	64.7	7.4	1.9
Mar. 1963	0	29.3	31.5	18.9	20.3
Dec. 1964	1.3	29.3	29.0	32.1	8.3
July 1965	1.3	29.3	29.0	33.7	6.7
June 1966	0.3	14.6	27.6	44.2	13.3
June 1967	0	13.9	22.3	54.2	9.6
June 1968	0	13.6	22.3	59.8	4.3
Northwest Branch Anacostia River near Colesville					
Nov. 1959	33.3	33.1	29.6	3.5	0.5
Mar. 1963	-	-	-	-	2.3
Dec. 1964	15	45.5	33.9	4.0	1.6
July 1965	15	44.8	33.3	4.2	2.7
June 1966	14.6	44.7	32.9	4.5	3.3
June 1967	14.6	44.1	32.3	5.2	3.8
June 1968	14.3	44.5	32.1	6.0	3.0

Exhibit 99. LAND USE IN ROCK CREEK-ANACOSTIA RIVER PROJECTS STUDY BASINS, 1966-68[(A-57)]

LAND USE, IN ACRES

Basin	Date	Farmland						Parks & Golf Courses				Residential					Public & Commercial		Construction		Total Basin Area
												Rural			Urban						
		Cropland	Pasture	Forest	Orchards	Ponds & Lakes	Impervious	Grass	Forest	Ponds	Impervious	Grass	Forest	Impervious	Grass	Impervious	Grass	Impervious	Residential	Other	
Williamsburg Run near Olney	June 1966	615	358	209	0	1	30	66	[illegible]	1	2	62	13	16	0	1	8	4	44	0	1440
	June 1967	603	303	206	0	1	25	64	[illegible]	1	2	74	12	16	0	[illegible]	8	4	102	7	1440
	June 1968	597	287	197	0	1	25	[illegible]	[illegible]	1	2	77	14	17	58	16	8	6	67	3	1440
N. Br. Rock Creek near Norbeck	June 1966	1808	1805	1439	42	4	90	332	73	[illegible]	11	264	114	11	7	4	9	6	100	35	6227
	June 1967	1795	1742	1434	42	4	90	332	73	[illegible]	11	272	114	13	11	5	9	12	170	30	6228
	June 1968	1789	1731	1425	42	4	90	332	73	[illegible]	11	281	118	14	68	23	14	15	116	12	6228
Manor Run near Norbeck	June 1966	12	245	122	57	0	10	22	21	0	4	34	30	15	0	4	0	5	36	1	648
	June 1967	12	210	121	55	0	9	21	21	0	4	34	30	15	[illegible]	3	0	5	69	1	648
	June 1968	12	184	118	55	0	9	21	21	0	4	34	30	15	19	5	6	7	75	3	648
Northwest Branch Anacostia River at Norwood	June 1966	320	442	574	2	3	25	0	0	0	0	48	49	16	0	0	33	15	5	0	1566
	June 1967	367	421	574	2	3	25	0	0	0	0	48	49	16	0	1	33	15	17	0	1569
	June 1968	367	406	574	2	3	25	0	0	0	0	59	50	18	0	1	43	20	5	0	1569
Nursery Run at Cloverly	June 1966	19	110	46	9	4	0	0	0	0	0	21	1	6	0	0	2	3	1	0	224
	June 1967	19	110	46	9	0	4	0	0	0	0	21	1	6	0	0	3	3	0	0	224
	June 1968	19	110	46	9	0	4	0	0	0	0	21	1	6	0	0	3	3	0	0	224
Bel Pre Creek at Layhill	June 1966	10	187	297	8	0	12	172	66	4	2	70	44	20	13	19	1	3	148	3	1082
	June 1967	9	190	274	8	0	12	169	66	4	2	70	44	20	25	43	0	4	144	6	1082
	June 1968	9	206	271	8	0	13	171	66	[illegible]	2	71	44	20	34	49	0	4	106	0	1082
Lutes Run at Lutes	June 1966	1	29	62	0	0	0	0	0	0	0	15	21	4	79	48	1	1	35	5	301
	June 1967	0	24	48	0	0	0	0	0	0	0	16	19	3	90	74	3	3	22	7	301
	June 1968	0	23	48	0	0	0	0	0	0	0	16	19	3	97	73	4	5	13	0	301
Northwest Branch Anacostia River near Colesville	June 1966	1966	4171	3544	168	11	212	729	344	[illegible]	36	870	369	211	147	102	74	28	442	10	13504
	June 1967	1970	4049	3452	168	11	209	725	338	[illegible]	36	921	399	270	176	149	73	33	456	59	13504
	June 1968	1932	4027	3421	166	11	210	727	335	10	36	907	412	206	221	161	84	40	397	12	13504

Exhibit 100(a). COMPILATION OF HYDROLOGIC AND SEDIMENT DATA, 1960-68(A-57)

Storm	Total runoff (cfs-days)	Storm runoff (cfs-days)	Suspended sediment (mg/l)	Sediment discharge (tons)	[a]Precipitation (inches)	Peak discharge
Williamsburg Run near Olney 2.25 sq mi						
Nov. 28-29, 1966	7.4	5.0	435	6.7	1.16	20
Jan. 7-9, 1967	14	6.2	195	7.3	(.26)	17
Jan. 27-28	15	11	4,660	197	1.02	71
Feb. 15-16	11	6.9	239	7.1	--	15
Mar. 6-8	70	62	2,230	421	2.68	242
May 7-8	19	15	1,270	65	1.82	51
June 22-23	2.9	1.5	2,430	19	1.14	16
July 20-21	3.9	2.5	266	2.8	1.02	16
Aug. 3-5	22	20	6,630	394	2.61	127
Aug. 24-25	60	58	1,690	274	3.20	405
Oct. 10,11	2.1	.8	106	.6	(.84)	6.7
Oct. 25-26	4.5	2.7	749	9.1	.90	26
Nov. 2-3	5.8	4.2	830	13.0	1.00	19
Dec. 10-12	30	23	864	70	(1.65)	49
Dec. 28-29	25	20	341	23	(1.50)	64
Jan. 14-15, 1968	51	46	378	52	1.50	115
Mar. 17-18	25	18	1,720	116	1.25	40
Apr. 24-25	5.3	2.1	245	3.5	(.97)	11
May 27-29	38	33	877	90	3.00	84
June 19-20	12	8.5	2,470	80	.96	69
June 26-28	20	16	2,260	122	1.84	70
Aug. 19-20	2.2	1.4	2,020	12	(.70)	15
Sept. 6	1.4	1.2	741	2.8	(.83)	9.6
Sept. 10-11	6.8	6.2	2,890	53	1.57	46
North Branch Rock Creek near Norbeck 9.73 sq mi						
Nov. 28-29, 1966	33	20	303	27	1.14	63
Jan. 27-28, 1967	55	38	2,150	320	.97	164
Feb. 15-16	40	20	70	7.6	--	41
Mar. 6-8	308	266	2,440	2,030	2.67	600
Mar. 15-16	65	38	296	52	1.02	98
May 7-8	90	86	992	241	1.94	187
June 22-23	14	7.5	503	19	1.17	33
Aug. 3-5	92	78	5,030	1,250	2.42	317
Aug. 24-25	218	203	3,720	2,190	3.06	823
Aug. 27-28	54	36	4,150	606	--	132
Nov. 2-3	22	14	253	15	.97	50
Dec. 3-4	68	50	365	67	(1.34)	104
Dec. 10-11	82	62	294	65	(1.66)	163
Jan. 14-15, 1968	204	182	741	408	1.49	413
Mar. 12-13	82	53	429	95	1.95	99
Mar. 17-18	113	66	603	184	1.20	139
May 27-29	138	118	955	356	2.96	223
June 16	17	12	2,980	137	(1.12)	123
June 19-20	48	37	2,720	353	.93	196
June 26-28	88	74	1,690	401	1.82	255
Sept. 10-11	30	27	4,120	334	1.80	126

Exhibit 100(b). COMPILATION OF HYDROLOGIC AND SEDIMENT DATA 1967-68$^{(A-57)}$

Storm	Storm runoff (cfs-days)	Storm runoff (cfs-days)	Suspended Sediment (mg/l)	Sediment discharge (tons)	^a Precipitation (inches)	Peak discharge
Manor Run near Norbeck 1.01 sq mi						
Nov. 28, 1966	4.4	4.0	1,090	13	1.29	23
Jan. 27-28, 1967	6.6	5.9	9,170	213	0.92	57
Mar. 6-8	47	44	3,540	449	2.61	182
Mar. 15-16	5.4	6.1	1,150	26	.95	26
Apr. 17-18	2.6	1.3	499	3.5	(.66)	5.0
May 7-8	16	14	6,160	266	1.96	66
June 22-23	4.6	4.1	9,820	122	1.50	110
Aug. 3-5	6.7	7.6	16,600	457	2.18	77
Aug. 24-25	37	36	13,800	1,380	5.28	199
Oct. 25	2.5	2.2	17,600	119	.97	42
Nov. 2	2.6	2.2	5,560	25	.98	13
Jan. 14-15, 1968	29	26	1,520	119	1.48	97
Mar. 12-13	9.4	5.9	1,680	36	1.73	21
Mar. 17-18	13.1	9.5	5,740	205	1.29	56
May 27-29	19	17	6,840	351	2.85	81
June 12-13	3.2	2.2	6,710	56	(.94)	19
June 16	10	9.3	19,000	513	(1.21)	101
June 19-20	11	9.3	16,600	493	[illegible]	194
June 26-28	10	6.0	10,400	280	1.61	114
July 2-5	6.5	5.2	13,200	231	(1.36)	95
Sept. 10-11	9.5	8.9	22,700	542	1.99	196
Northwest Branch Anacostia River at Norwood 2.40 sq mi						
Mar. 17, 1967	14	11	344	13	.95	44
May 7-8	23	16	3,050	188	2.08	75
June 22-23	3.7	2.6	2,200	22	1.30	36
Aug. 4-5	14	12	6,060	229	2.54	206
Nov. 2-3	2.8	2.3	306	2.1	1.06	13
Jan. 14-15	46	42	348	43	1.54	139
Mar. 12-13	16	14	556	23	1.90	41
Mar. 17-18	30	21	728	59	1.56	69
May 27-29	39	33	693	73	2.92	121
June 19-20	14	10	2,080	79	1.04	159
June 27-28	12	7.8	2,450	88	1.72	102
Nursery Run at Cloverly 0.35 sq mi						
Nov. 28, 1966	.94	.64	39	0.1	1.15	2.6
Jan. 27-28, 1967	1.2	.59	186	0.6	0.72	4.0
Mar. 6-7	7.1	6.1	480	9.2	2.55	35
Mar. 15	1.1	0.60	34	0.1	.81	2.9
May 7-8	3.5	2.4	106	1.0	2.00	9.6
June 22	1.1	0.8	370	1.1	1.48	15
July 29-30	1.9	1.4	1,790	9.7	(1.47)	31
Aug. 3-5	4.9	3.7	1,130	15	2.98	51
Aug. 24-25	11	9.6	1,180	35	3.67	216
Oct. 25-26	1.1	.54	202	.6	.95	8.7
Nov. 2	.83	.60	45	.1	1.03	3.7
Jan. 14-15, 1968	7.1	6.4	511	9.8	1.61	29
Mar. 12-13	2.0	1.0	74	.4	1.76	4.6
Mar. 17-18	3.6	2.4	62	.6	1.68	6.8
May 27-28	3.3	2.3	146	1.3	3.15	8.7
June 19	2.3	2.0	2,740	17	1.24	53
June 26-28	1.4	.61	22	0.1	1.28	2.9
Sept. 10-11	.82	.54	30	.2	1.41	6.4

Exhibit 100(c). COMPILATION OF HYDROLOGIC AND SEDIMENT DATA, 1967-68(A-57)

Storm	Storm runoff (cfs-days)	Storm runoff (cfs-days)	Suspended sediment (mg/l)	Sediment discharge (tons)	[a]Precipitation (inches)	Peak discharge
Bel Pre Creek at Layhill 1.60 sq mi						
Oct. 18-19, 1966	35	34	1,320	125	2.45	84
Nov. 28-29	13	12	1,540	54	1.29	63
Jan. 27-28, 1967	9.5	8.3	3,740	96	.75	56
Mar. 6-8	58	55	2,370	378	2.55	193
Mar. 15-16	18	15	1,170	57	.85	52
Apr. 17-18	3.8	2.5	1,070	11	(.66)	11
May 7-8	34	30	1,800	165	2.01	96
June 22-23	10	9.0	4,080	109	1.49	130
July 20-21	7.3	6.6	2,880	57	.96	85
Aug. 3-5	26	24	7,390	519	2.28	156
Aug. 24-25	67	64	2,460	445	3.68	338
Oct. 25-26	12	11	4,010	130	1.14	135
Nov. 2-3	9.3	8.3	1,230	31	1.02	58
Dec. 3-4	31	28	358	30	(1.42)	68
Dec. 28-29	29	27	600	47	(1.48)	81
Jan. 14-15, 1968	48	45	478	62	1.36	158
Mar. 12-13	25	22	874	58	1.79	63
Mar. 17-18	35	28	1,280	119	1.49	86
May 27-29	44	40	976	116	2.76	106
June 16-17	17	15	2,270	104	(1.21)	137
June 19-20	16	14	2,450	106	1.04	178
June 27-28	20	18	4,520	244	1.70	134
July 2-3	16	15	4,120	178	(1.36)	114
Sept. 6	2.7	2.5	892	6.5	(.76)	29
Sept. 10-11	9.7	9.2	2,060	54	1.50	104
Lutes Run at Lutes 0.47 sq mi						
Nov. 28, 1966	3.4	3.2	1,740	16	1.17	23
Jan. 27, 1967	2.9	2.6	10,900	85	.74	44
May 7	9.1	8.0	2,730	67	2.06	43
June 22	5.0	4.8	4,440	60	1.39	189
July 20	5.9	5.8	4,580	73	1.42	194
July 29-30	3.7	3.5	2,400	24	(1.08)	153
Aug. 3-5	13	12	2,850	100	2.67	221
Aug. 19	2.7	2.5	4,660	34	(1.42)	88
Oct. 25-26	2.6	2.3	4,560	32	1.32	101
Nov. 2	3.0	2.9	728	5.9	.97	26
Jan. 14-15, 1968	12	11	617	20	1.45	65
Mar. 17-18	6.0	4.7	1,850	30	1.84	51
May 27-29	10	9.1	1,110	30	3.13	75
June 19-20	6.7	6.2	3,370	61	.70	270
July 2-3	9.2	8.5	2,130	53	(2.05)	218
Sept. 2	.88	.82	2,310	5.5	(.32)	48
Northwest Branch Anacostia River near Colesville 21.1 sq mi						
Nov. 28-30, 1966	94	70	666	169	1.21	149
Dec. 18-19	41	16	81	9	(.34)	41
Jan. 27-28, 1967	99	80	1,950	520	.75	149
Feb. 14-17	142	67	501	192	--	107
Mar. 6-8	616	550	1,720	2,860	2.55	1,300
Mar. 15-17	154	97	580	241	.85	158
Apr. 6-7	44	13	73	8.6	(.66)	44
May 7-9	264	216	1,570	1,120	1.98	498
June 22-23	64	51	4,020	695	1.39	316
July 2-4	80	59	2,150	465	(1.65)	195
July 20-21	49	38	3,420	453	.91	291
July 29-31	40	25	3,020	326	(.68)	131

Exhibit 100(d). COMPILATION OF HYDROLOGIC AND SEDIMENT DATA, 1967-68$^{(A-57)}$

Storm	Total runoff (cfs-days)	Storm runoff (cfs-days)	Suspended sediment (mg/l)	Sediment discharge (tons)	[a]Precipitation (inches)	Peak discharge
	Northwest Branch Anacostia River near Colesville 21.1 sq mi					
Aug. 3-6, 1967	249	220	2,310	1,550	2.58	762
Aug. 19-20	45	30	1,560	192	(1.30)	102
Aug. 24-25	635	607	2,150	3,690	3.67	1,745
Oct. 10-11	27	18	329	24	(.84)	61
Oct. 25-26	57	44	2,050	313	1.06	294
Nov. 2-3	58	42	843	132	1.02	119
Dec. 3-4	196	164	1,100	582	(1.35)	164
Dec. 10-12	262	211	861	609	1.61	380
Jan. 14-15, 1968	488	444	602	793	1.42	325
Feb. 2-3	61	24	334	55	(.38)	69
Mar. 12-14	210	145	1,120	636	1.86	288
Mar. 17-19	327	221	1,000	885	1.63	454
Mar. *23-24	68	26	136	25	(.10)	72
Apr. 24-25	53	26	245	35	(.94)	68
May 27-29	310	[illegible]	1,830	1,530	2.87	511
June 12-13	59	36	1,720	274	(1.15)	160
June 16-18	101	69	1,690	462	(1.60)	190
June 19-20	174	146	2,210	1,038	1.09	574
June 26-28	122	92	2,960	975	1.47	306
July 2-3	98	77	2,240	593	(1.45)	322
Sept. 6-7	18	13	247	12	(.84)	54
Sept. 10-11	40	33	4,060	329	1.31	176

[a] Precipitation is average value computed by isohyetal method except those values in parentheses, which are measurements at the nearest rain gage.

Exhibit 100(e). HYDROLOGIC AND SEDIMENT DATA OF BEL PRE CREEK AT LAYHILL, MD., 1963-66(A-57)

Storm	Total runoff	Storm runoff	Suspended sediment	Sediment discharge	Precipitation	Peak discharge
	cfs-days	cfs-days	(mg/l)	(tons)	inches	(cfs)
Mar. 6-7, 1963	27	25	384	26	.87	54
Mar. 12-13	21	19	145	8.2	1.46	41
Mar. 20-21	7.4	5.4	115	2.3	.86	24
June 2-3	23	22	274	17	2.95	61
Aug. 20-21	20	20	204	11	2.75	102
Sept. 29	4.5	4.2	107	1.3	2.10	18
Nov. 6-7	40	38	150	14	3.30	80
Jan. 9-10, 1964	27	26	165	12	1.16	117
Aug. 3	1.3	1.2	256	0.9	1.95	14
Dec. 27-28	11	10	125	3.7	.72	31
Mar. 5-6, 1965	75	71	894	181	2.95	260
Aug. 26-27	71	70	4,780	917	2.81	410
Jan. 6, 1966	6.3	4.5	1,180	20	.89	22
Feb. 13	65	63	2,250	394	1.73	180
Apr. 12-13	23	19	1,950	121	2.20	62
July 5-6	5.6	4.1	1,650	25	.37	44
Aug. 11	3.2	2.6	4,510	39	.91	49
Sept. 14	59	55	2,100	334	5.46	370

HYDROLOGIC AND SEDIMENT DATA OF LUTES RUN AT LUTES, MD., 1963-66

Storm	Total runoff	Storm runoff	Suspended sediment	Sediment discharge	Precipitation	Peak discharge
	cfs-days	cfs-days	(mg/l)	(tons)	inches	(cfs)
Feb. 20-21, 1963	3.3	2.7	4,040	36	.63	12
Mar. 6	6.2	4.7	15,700	262	1.36	27
Mar. 11-12	8.2	4.7	4,070	90	1.54	18
Mar. 19-20	4.4	1.8	2,950	35	.88	6.7
June 2-3	9.1	8.1	8,710	214	2.93	50
Nov. 6-7	9.7	8.8	8,440	221	2.80	37
Jan. 9, 1964	7.7	7.1	10,700	223	1.16	42
Aug. 3	3.4	2.8	8,930	82	1.95	48
Feb. 7-8, 1965	7.6	5.8	4,630	95	1.38	36
Mar. 26	4.8	3.6	2,930	38	1.26	46
Oct. 7-8	37	34	3,520	352	3.45	E350
Feb. 13, 1966	18	12	5,970	290	1.71	E170
Aug. 11	3.4	2.4	4,680	43	1.00	E67

E Estimated.

Exhibit 100(f). HYDROLOGIC AND SEDIMENT DATA OF NORTHWEST BRANCH ANACOSTIA RIVER NEAR COLESVILLE, MD., 1960-66 (A-57)

Storm	Total runoff	Storm runoff	Suspended sediment	Sediment discharge	[a]Precipitation	Peak discharge
	cfs-days	cfs-days	(mg/l)	(tons)	inches	(cfs)
Sept. 11-13, 1960	275	239	677	503	3.32	630
Jan. 1-2, 1961	182	160	381	187	3.34	260
Feb. 18-20	563	428	621	944	.41	538
Feb. 22-24	318	183	525	451	1.07	399
Apr. 12-14	524	434	468	664	2.01	1,050
Aug. 26-27	99	80	1,780	475	1.06	307
Dec. 18	85	58	549	126	1.09	224
Jan. 6-7, 1962	160	128	553	239	1.80	225
Feb. 24	50	20	96	13	.14	106
Feb. 26-28	338	254	987	901	1.74	600
Mar. 11-13	580	478	882	1,400	1.12	798
Mar. 31 to Apr. 2	209	137	429	242	1.46	307
May 23-24	125	98	2,260	757	1.35	444
Oct. 4-5	32	23	440	38	2.31	70
Nov. 9-11	134	110	1,060	382	2.14	316
Nov. 18-19	43	25	198	23	.94	70
Nov. 21-22	140	114	646	244	1.08	252
Jan. 11-14, 1963	239	188	426	275	0.81	146
Jan. 19-21	89	47	150	36	.37	61
Feb. 11-13	140	92	638	264	.68	149
Feb. 19-22	148	104	1,910	764	.58	327
Mar. 5-7	383	306	2,140	2,100	.96	642
Mar. 12-14	274	206	902	667	1.12	335
Mar. 16-20	257	131	262	182	1.26	151
May 29-31	32	11	185	16	.83	32
June 2-4	244	203	2,230	1,470	3.53	386
June 21-22	23	10	64	4	.80	34
July 14-16	24	13	216	14	1.03	28
Aug. 13-15	33	28	5,390	480	1.12	69
Aug. 19-22	220	202	6,880	4,090	2.64	684
Aug. 29-30	11	3.1	135	4	.30	17
Sept. 29-30	76	66	3,960	613	2.39	171
Nov. 1-3	28	14	79	6	1.22	26
Nov. 6-8	343	314	2,080	1,930	3.30	619
Nov. 23-24	43	28	620	72	.82	71
Nov. 29 to Dec. 1	254	235	1,430	981	2.00	261
Dec. 8-10	94	58	1,220	310	.97	151
Jan. 9-11, 1964	369	294	1,930	1,920	1.13	614
Jan. 20-22	227	152	418	256	.40	272
Jan. 25-26	223	171	1,320	797	.97	534
Feb. 6-8	185	119	1,430	712	.86	166
Mar. 2-5	245	115	311	206	.36	143
Mar 21-23	197	122	884	470	1.36	240
Apr. 30 to May 1	153	88	1,290	534	.70	307
May 13-14	42	11	432	49	.30	61
July 8-9	20	11	1,040	56	.80	38
July 13-14	25	15	1,360	92	.88	72
Aug. 2-4	32	20	3,080	267	1.15	94
Sept. 29 to Oct. 1	39	25	1,020	107	2.46	65
Nov. 25-26	63	48	2,990	508	1.51	135
Dec. 4-7	62	30	1,030	172	.77	103
Dec. 12-14	158	134	2,630	1,120	1.61	394
Dec. 26-29	125	76	1,200	408	1.08	171
Jan. 8-11, 1965	117	65	187	59	1.16	49
Jan. 22-26	234	156	948	599	.83	263
Feb. 7-9	253	217	3,500	2,390	1.36	513
Feb. 25-27	62	29	215	38	0.58	51
Mar. 5-8	647	575	2,700	4,720	2.91	1,210

Exhibit 100(g). HYDROLOGIC AND SEDIMENT DATA OF NORTHWEST BRANCH ANACOSTIA RIVER NEAR COLESVILLE, MD., 1960-64$^{(A-57)}$

Storm	Total runoff	Storm runoff	Suspended sediment	Sediment discharge	[a]Precipitation	Peak discharge
	cfs-days	cfs-days	(mg/1)	(tons)	Inches	(cfs)
Mar. 25-27, 1965	200	140	1,280	693	.86	442
May 28-30	37	13	270	27	.26	39
June 2-4	44	22	530	63	1.03	45
July 11-12	59	47	4,160	663	1.40	508
Aug. 21-23	16	9	116	5	1.10	22
Aug. 26-28	240	230	5,940	3,850	2.10	792
Sept. 24-25	17	10	1,570	72	.70	69
Oct. 7-9	379	361	2,970	3,040	3.30	1,010
Jan. 6-7, 1966	49	34	310	41	.82	59
Feb. 10-15	741	649	1,480	2,960	1.74	1,050
Feb. 28 to Mar. 2	333	275	1,710	1,540	1.20	800
Mar. 24-25	40	18	222	24	.76	61
Apr. 12-14	220	178	1,560	924	2.16	282
Apr. 22-23	34	9	54	5	.53	26
Apr. 30 to May 2	143	80	394	152	1.01	127
May 18-20, 1966	78	48	1,530	322	1.56	82
May 27-30	115	73	2,040	632	1.22	206
June 28-29	12	4.4	1,230	40	--	32
July 5-6	19	12	1,540	79	0.75	53
July 15	5.1	3.1	1,740	24	.22	40
Aug. 11-12	11	8.7	2,260	67	.90	13
Sept. 14-16	681	669	2,090	3,840	6.45	2,100
Sept. 20-22	146	122	1,420	560	1.76	358
Sept. 29-30	45	20	568	69	.42	87

[a] From Brighton Dam non-recording gage September 1960 to March 1964. From Norwood South non-recording gage thereafter.

by subtracting the base flow from the measured flow. Base flow was determined by drawing a line between the initial rise of the stage hydrograph and the point at which it levels out again after the storm. Suspended sediment concentration was determined weekly at three stations and during storms at the remaining six. Exhibit 101 gives the rainfall distribution.

Urban Development and Runoff -

Exhibit 102 shows a comparison of the runoff from Bel Pre Creek and the Northwest Branch Anacostia River both before and during construction activities covering 15 percent of the 1.69 square mile drainage basin of the Bel Pre Creek. It can be seen that there is an increase of runoff due to construction activities for small rainfalls, while the runoff for larger storms remains essentially unchanged.

Average streamflow also remained essentially the same. This is illustrated in Exhibit 103, a comparison of cumulative discharge for the Northwest Branch near Colesville, an area undergoing considerable construction activity, and Seneca Creek, an essentially rural area. These two statements are reconciled by changes in the amounts and timing of the groundwater inflows.

Urban Development and Sediment Transport -

Exhibits 104 through 106 show the changes in suspended sediment discharge during the urbanization of three basins. Exhibits 104 and 105 show the effects of construction while Exhibit 106 shows the eventual decrease as the area is finally urbanized. Exhibit 107 gives the sediment runoff relationships for six of the secondary basins. Manor Run has an area of 1.01 square miles, of which 11 percent is under construction. This is the second largest percentage of all the basins. (Bel Pre Creek had the largest, 14 percent). Nursery Run is the smallest basin,

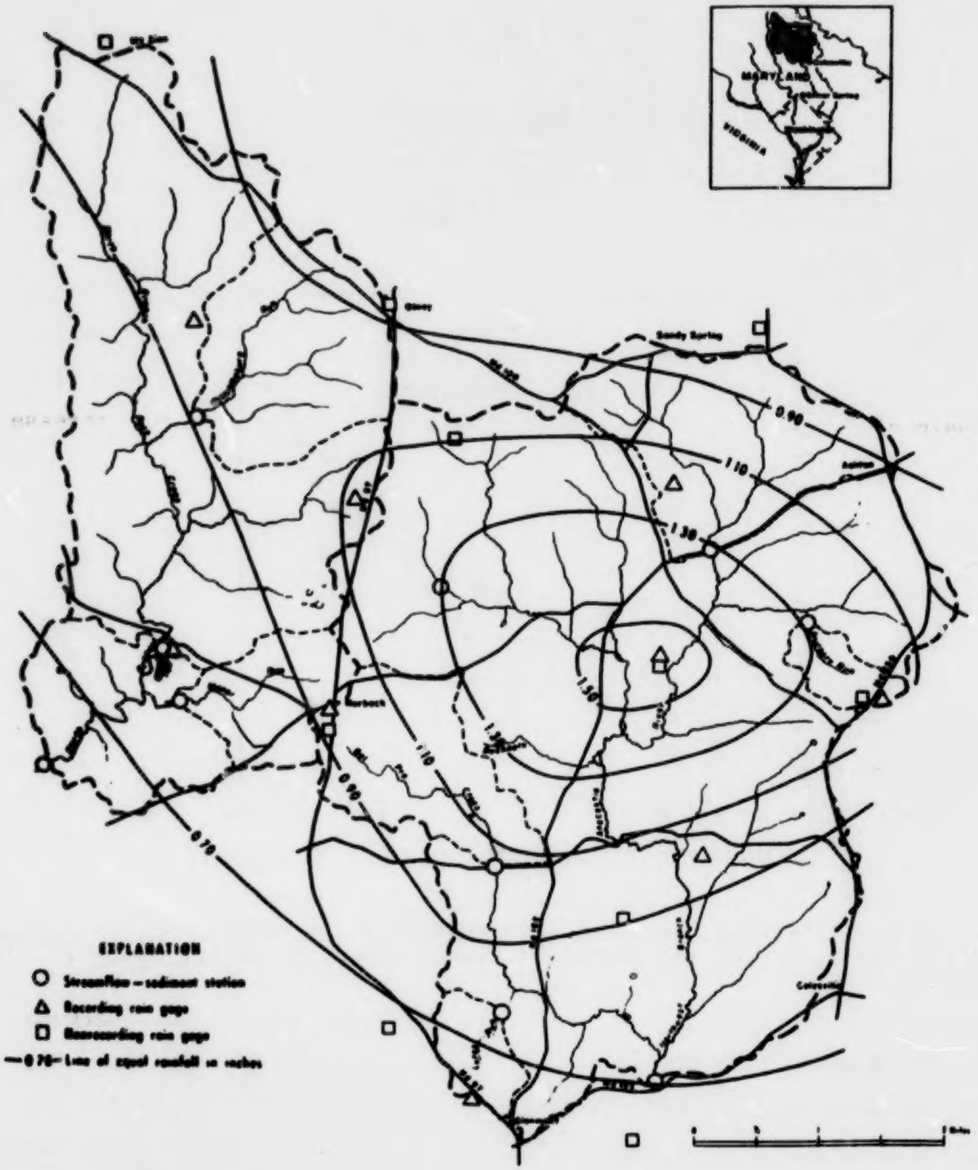
MARYLAND
VIRGINIA
Olney
Sandy Spring
Ashton
Norbeck
Colesville
0.90
1.10
1.30
1.50
0.70
EXPLANATION
○ Streamflow—sediment station
△ Recording rain gage
☐ Nonrecording rain gage
—0.70— Line of equal rainfall in inches

Exhibit 101. Rainfall Distribution of June 19, 1968, in the North Branch-Rock Creek and Upper Northwest Branch-Anacostia River Basins, Md.(A-57)

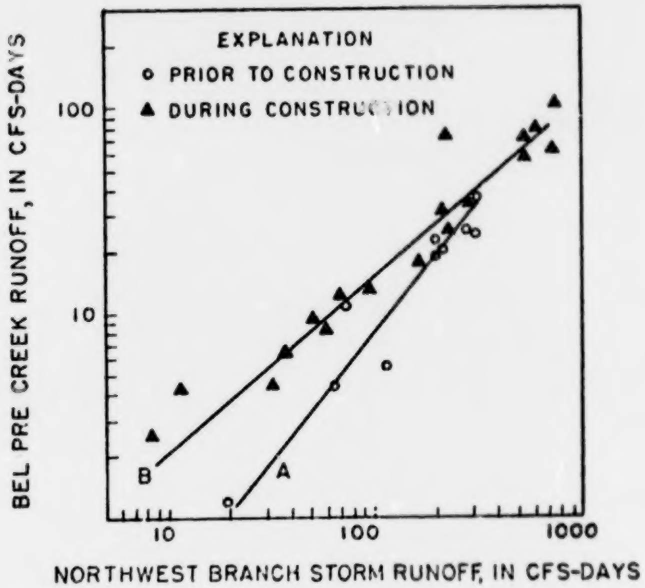

Exhibit 102. Relation Between Storm Runoff of Bel Pre Creek and Northwest Branch-Anacostia River, 1963-67 (A-57)

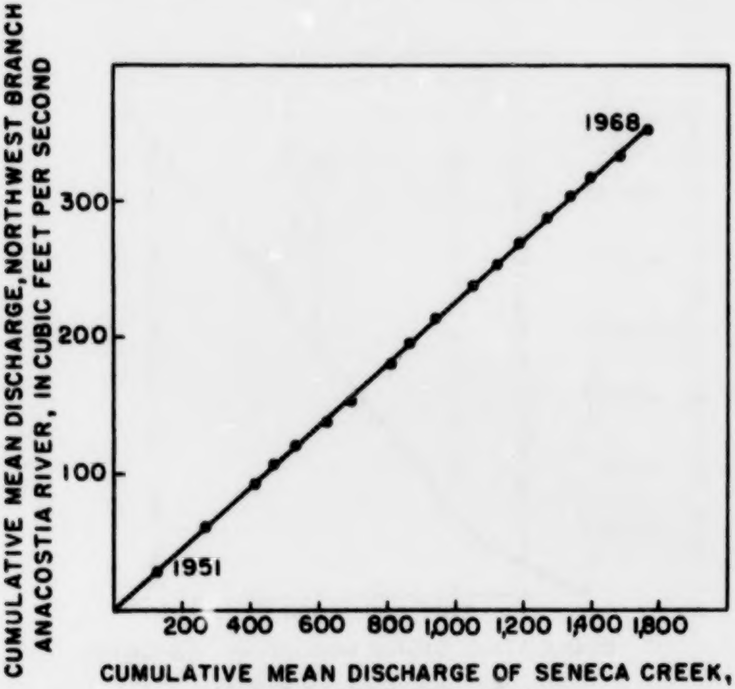

Exhibit 103. Cumulative Plot of Annual Mean Discharge of Northwest Branch-Anacostia River Near Colesville and Seneca Creek at Dawsonville, Md., 1951-68 (A-57)

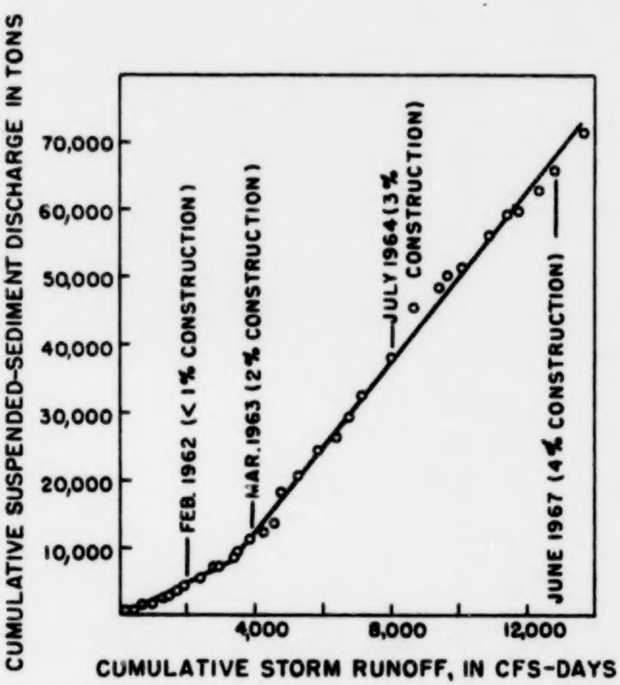

Exhibit 104. Cumulative Plot of Suspended-Sediment Discharge and Storm Runoff of Northwest Branch-Anacostia River Near Colesville, Md., 1960-68 (A-57)

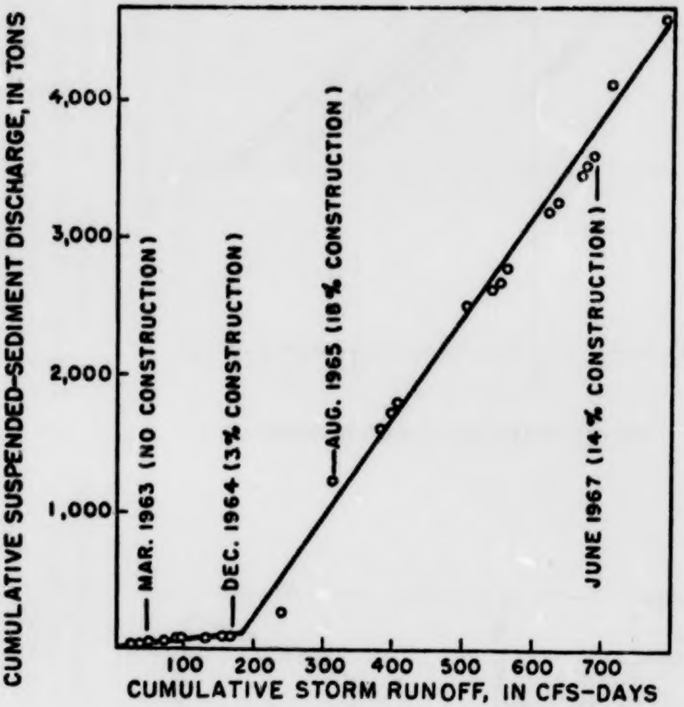

Exhibit 105. Cumulative Plot of Suspended-Sediment Discharge and Storm Runoff of Bel Pre Creek at Layhill, Md., 1963-67(A-57)

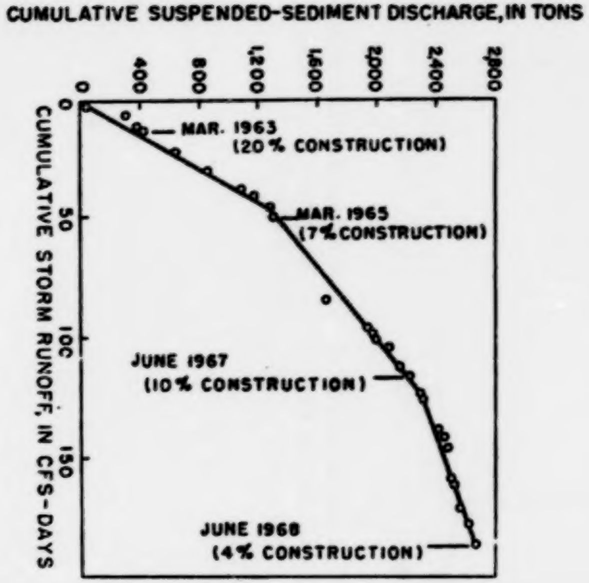

Exhibit 106. Cumulative Plot of Suspended-Sediment Discharge and Storm Runoff or Lutes Run at Lutes, Md., 1963-68 (A-57)

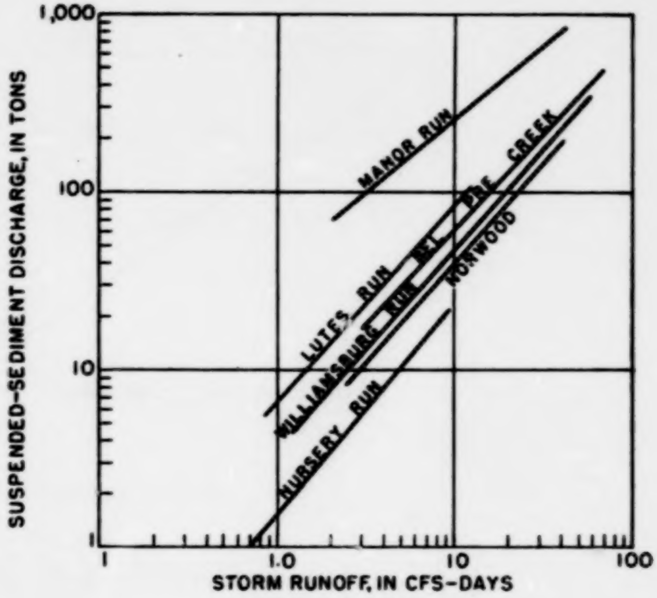

Exhibit 107. Relation Between Suspended-Sediment Discharge and Storm Runoff of Rock Creek-Anacostia River Project Basins of Less than Three Square Miles, 1967-68 (A-57)

.35 square miles, and is without construction. Average sediment concentrations are computed to be 10,000 mg/l in Manor Run and 700 mg/l in Nursery Run.

Not all cases were as clear cut as those presented in Exhibits 105 through 107. Other factors were found that influenced the sediment yield-runoff relationships. These include mean air temperature, total precipitation, runoff/precipitation rates and peakedness ratio. The peakedness is the ratio of peak discharge in cfs to storm runoff in cfs-days. It is a general indicator of the intensity of the rainfall and the response of the drainage system. When adjusted for this ratio, the sediment discharge curves of at least one basin showed a markedly better fit, as shown in Exhibits 108 and 109.

Another important consideration was difference of sediment yields during summer and winter. This is due to the fact that in the winter the land, though still exposed, is usually frozen or too wet to work. The sediment surface then gradually increases in particle size as the fines are carried away. Eventually a protective surface forms which is composed of relatively large soil particles that are not easily carried off and shield the lower surface from active erosion. During the summer, this does not occur, since the soil is constantly being moved.

Exhibit 110 shows the variations of unit sediment yield over the basins studied. An analysis was carried out to determine what conditions caused these variations. It was determined that two parameters greatly reduced the variations: land slope and the percentage of the total construction within 300 feet of the channel. When adjusted for these parameters, a much closer fit was obtained (see Exhibit 111).

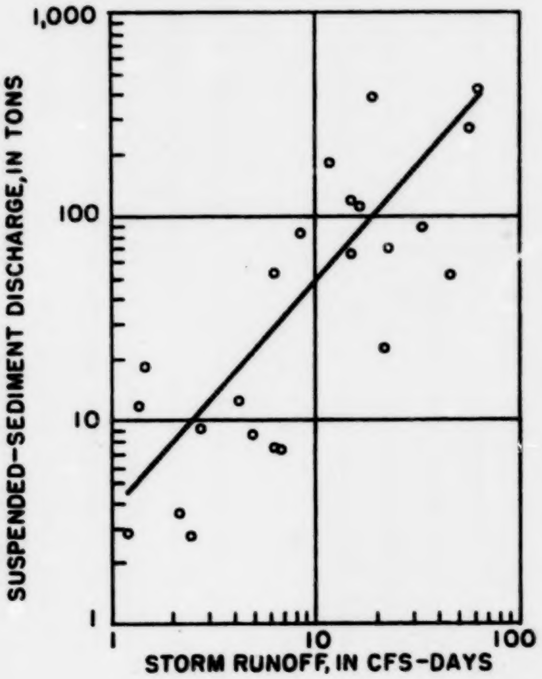

Exhibit 108. Relation Between Suspended-Sediment Discharge and Storm Runoff for Storms in Williamsburg Run Near Olney, Md., 1967-68(A-57)

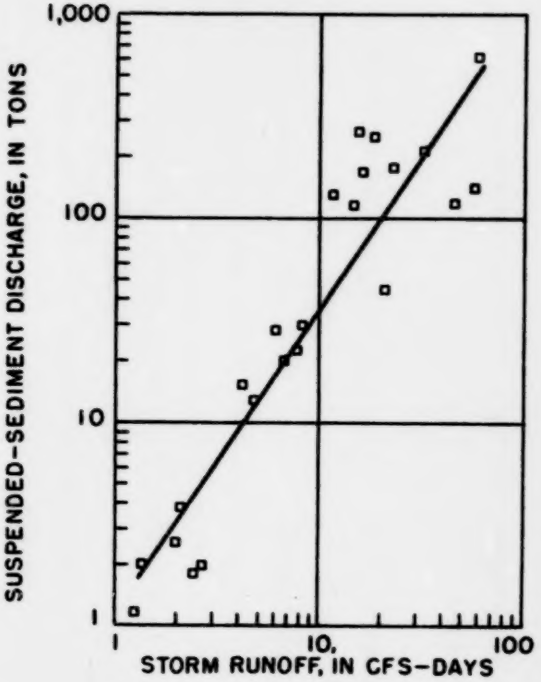

Exhibit 109. Relation Between Suspended-Sediment Discharge and Storm Runoff in Williamsburg Run After Adjustment for Peakedness Ratio (A-57)

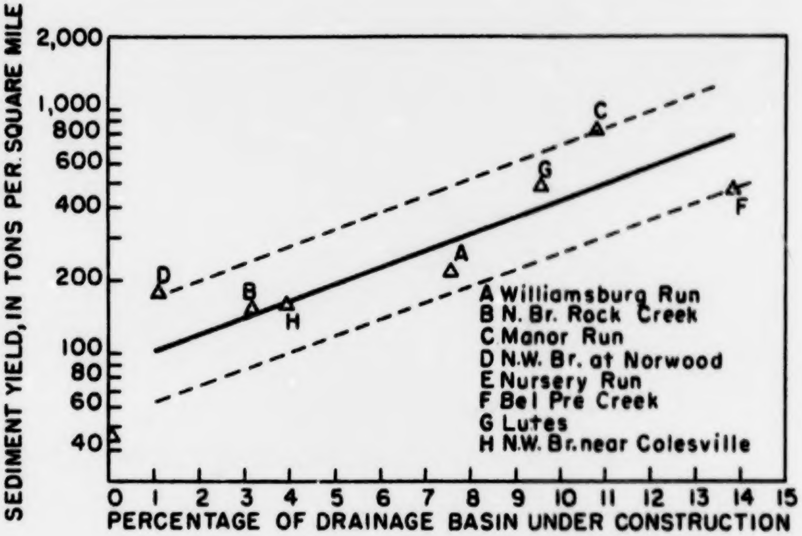

Exhibit 110. Relation Between Sediment Yield of Three 1967 Growing Season Storms and Percentage of Land Under Construction Within the Study Basin (A-57)

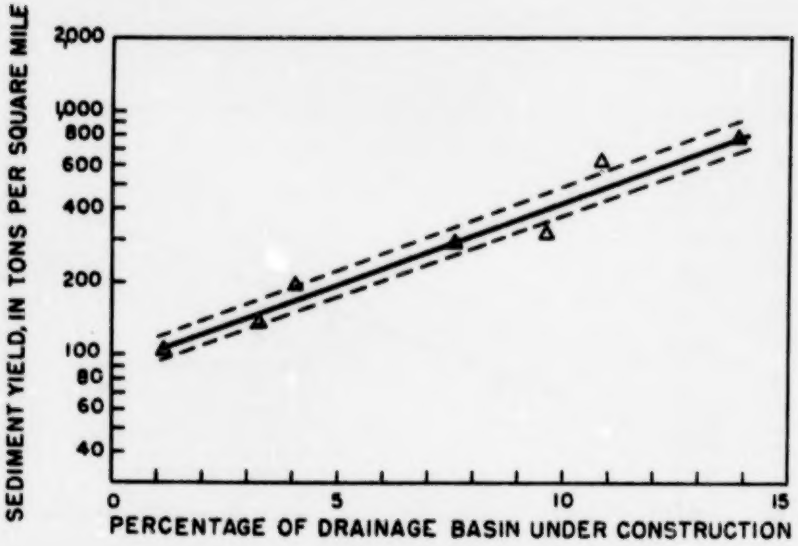

Exhibit 111. Relation Between Sediment Yield
and the Amount of Construction After Adjustments
for Percentage Construction Within 300 ft. of Stream Channels (A-57)

This paper concluded that although construction increases the sediment loads to streams, it could be reduced to at least a small degree by keeping it further from the stream channels and at a shallow slope. This was, of course, only a report of the first phase. The second phase will involve a more detailed study of control measures.

Case 15. Coyote Creek and Cold Creek Sediment Studies near South Lake Tahoe, California

Source -

Unpublished information obtained through personal communications with (1) California Regional Water Resources Control Board (Lahontan Region), and (2) Department of Plans and Permits, City of Lake Tahoe, California. May 1974.(A-11)

Purpose -

The Lahontan Regional Office of the State Water Resources Control Board took measurements upstream and downstream of construction sites on four local watersheds in an effort to determine (1) the effects of construction on the suspended sediment concentration of the streams, and (2) the effects of suspended sediment on the population of silt-sensitive insects in or near the stream bed.

Site Location/Description -

The measured portions of all four watersheds are on the southern side of Lake Tahoe, lying within El Dorado County and partly within the city limits of South Lake Tahoe, California.

Topography -

Generally mountainous except for flat areas near the lake. Estimates of the slope for specific construction sites:

Coyote Creek area - 5 to 10 percent
Cold Creek area - 10 to 12 percent
Lonely Gulch area - 30 to 45 percent (highway construction)

Soil Type -

Decomposed granite; a loose, sandy material with little adhesive characteristics.

Land Uses/Ground Cover -

These differ for the four watersheds. The uses of areas where measurements were taken can be roughly characterized as follows:

Coyote Creek--residential
Cold Creek--control stream, some residential area
Heavenly Valley--ski area (no upstream measurements)
Lonely Gulch--general land use not specified, but contained some road construction

The Coyote Creek watershed (for which land-use data are most complete) drains some 1,020 acres.

Climate/Rainfall

After snowmelt, only one or two rains occur during summer and fall. (Average precipitation not quoted for South Lake Tahoe, but at Tahoe City, about 20 miles northwest, it is about 30 inches annually.)

Parameters Measured -

Two types of measurements were taken: physical and biological.

Physical parameters:	automatic gaging to yield daily average flows (gage heights)
	suspended sediment concentrations (weekly)

Biological parameters: Number of larvae per square foot (based on sample counts) for the following orders:

- flat worms (tricladia)
- segmented worms (oligochaeta)
- May flies (ephemeroptera)
- stone flies (plecoptera)
- caddis flies (tricoptera)
- common flies (diptera)

These insects spend most of their life cycles in streams, providing food for fish, birds, etc.

In addition, a coarse measure of land use for two of the watersheds was obtained by examining city and county records to determine the number of sewer hook-ups during the time period covered by the physical and biological measurements. Since all buildings are required to be connected to a central sewerage system, the number of building sewer connection permits issued provides a rough indication of the amount of residential and commercial construction.

Time Frame -

November 1972 - January 1974 (approximate)

Results -

The data on suspended sediment and gage height were provided by the Lahontan Regional Office of the California Water Resources Control Board. This information is given in Exhibit 112.

The following reductions were observed in concentration of insect larvae (number of larvae per square foot of streambed) based on upstream and downstream of construction sites:

Order	Observed downstream concentration was approximately:
Tricladia (flat worms)	1/3 of upstream concentration
Oligochaeta (segmented worms)	1/8 of upstream concentration
Ephemeroptera (May flies)	3/4 of upstream concentration
Plecoptera (stone flies)	1/4 of upstream concentration
Tricoptera (caddis flies)	1/10 of upstream concentration
Diptera (common flies)	1/3 of upstream concentration

The following information about the state of development in the

Exhibit 112. SEDIMENT CONCENTRATION AND GAGE HEIGHT AT FOUR STATIONS COYOTE CREEK, CALIFORNIA(A-11)

	SUSPENDED SEDIMENT CONC. (PPM)			GAGE HEIGHT (FT)			Number Samples
	Mean	Std. Dev.	Range	Mean	Std. Dev.	Range	
COYOTE CREEK							
Upstream	6.00	22.09	0-139	0.24	0.57	0.01-0.64	38
Downstream	7.04	12.23	0-51	0.18	0.18	0.01-0.84	35
COLD CREEK							
Upstream	38.4	68.9	1.89-350	0.68	0.148	0.50-0.93	47
Downstream	68.0	190.8	0.38-1107				47
LONELY GULCH							
Upstream	3.58	5.91	0-33	0.23	0.22	0.01-0.79	38
Downstream	104.6	304.2	0-1378	0.22	0.195	0.04-0.80	40
HEAVENLY VALLEY							
Downstream	58.9	106.3	0-651	0.49	0.266	0.01-0.90	65

Coyote Creek and Cold Creek watersheds was obtained from records in the Department of Plans and Permits of the City of South Lake Tahoe.

Total Lots on Plat Book	Total Number of Sewer Connections	Sewer Connection Permits issued during the Period Fall 1972-Spring 1974	Prior Connections
630	15	13	2
844	159	27	132

Note: The above figures are intended to provide only a gross indication of the state of residential development in the watersheds before the measurement program began, and the amount of development during the period in which sediment measurements were taken. Time did not permit detailed verification of these counts. Similar data were not obtained for the Lonely Gulch and Heavenly Valley measurement areas.

Case 16. Stream Channel Enlargement Due to Urbanization

Source -

Hammer, J. R., "Stream Channel Enlargement Due to Urbanization," Journal of Water Resources Research, Vol. 8, No. 6, December, 1972.(A-22)

Purpose -

The purpose of this study was to study the effects of urbanization on stream channel enlargement and the water quality of the channel.

Site Location/Description -

The study took place in the Pennsylvania portion of the Philadelphia Metropolitan Area which consists of the city of Philadelphia, plus Bucks, Montgomery, Delaware, and Chester Counties. Seventy-eight watersheds (1 to 6 sq. mi. in size) were covered by this study. Some degree of urbanization in the form of large scale residential, commercial, or industrial development was taking place in 50 of the watersheds while in the remaining 28 watersheds most activity was rural in nature.

Study Methods -

For better results each watershed was divided into 40-acre size grid squares; for each grid square the different characteristics were measured and recorded. Land use activities were divided into 17 categories within the grid square. The major emphasis was, however, placed on the land in impervious uses and the impervious areas were divided into three categories: (a) area of all paved streets, highways, rural roads, expressways, and the area of paved sidewalks; (b) area of single-family or two-family houses (the houses themselves), paved driveways, walks, and patios, and adjoining areas such as garages, sheds and small barns; and (c) the area covered by commercial buildings, apartment houses, factories, airport runways, shopping centers, row houses, parking lot, etc.

Each impervious-area category was further divided into three subcategories: (i) area less than 4 years old, (ii) area 4 - 15 years old, and (iii) area greater than 15 years old.

The non-impervious area connected with street storm sewage was also taken into consideration.

Parameters Measured -

- Average land slope
- The length and average slope of the flow path from the grid square to the point at which the flow reached the stream channel; and also from the grid square to the mouth of the watershed
- Man-made alterations
- The channel measurements for overall channel width, depth and cross-sectional area
- Watershed shape index
- Soil drainage index

Results -

The results of this study of the effects of urbanization on stream channel size are given in Exhibit 113. These results were computed through regression analysis of land use in a one-square mile basin in relation to channel enlargement.

Discussion of Results -

The results show that the process of urbanization causes an increase of the peak flow rates due to the increase of impervious area, which increases the volume of runoff, causing the channel enlargement which results in further reduction in the aesthetic and recreational values of the stream and the deterioration of the water quality.

Exhibit 113. CHANNEL ENLARGEMENT EFFECTS ON LAND USES IN A 1-SQUARE-MILE BASIN (A-22)

	Δ Factor Factor by which channel size was increased (1.0 no change)
Land in cultivation	1.29
Wooded land	0.75
Land in golf courses	2.54
Impervious area <4 years old and unsewered street and house area	1.08
Area of houses fronting on sewered streets	
Houses 4 - 15 years old	3.36
Houses 15 - 30 years old*	4.15
Houses >30 years old**	1.08
Area of sewered streets	
Steets 4 - 15 years old	4.20
Streets 15 - 30 years old*	5.16
Streets >30 years old**	3.76
Other impervious area	
Area 4 - 15 years old	6.26
Area >15 years old	7.99
Nonimpervious developed land plus impervious area <4 years old and unsewered streets and houses	1.08
Open land (residual category)	0.90

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*Built after 1940

**Built before 1940

Case 17. Joint Construction Sediment Control Project, Columbia, Maryland

Source -

Hittman Associates, Inc., Joint Sediment Control Project, Columbia, Maryland, HIT-546, Prepared for Environmental Protection Agency Office of Research and Development, Columbia, Maryland, June 1973.(A-17)

Purpose -

This project consisted of three phases: 1) the implementation and evaluation of erosion control practices in two adjacent sub-basins; 2) the construction and operation of a storm retention pond to control pollution due to storm runoff; 3) the construction and operation of methods for the handling and ultimate disposal of sediment. These three phases were combined with a monitoring program to determine the effects of urbanization on the hydrology and water quality of the adjacent streams.

Site Description -

This project was conducted in a 190-acre demonstration area, the village of Long Reach. This village is part of the planned city of Columbia, Maryland. Its location is shown on Exhibit 114 and the watershed boundaries are given in Exhibit 115. At the beginning of the project, the area was mostly rural. Land development plans are shown in Exhibit 116 and listed in Exhibit 117. The topography is generally hilly, with dense forests growing along the major stream channels. Two sub-basins, shown in Exhibit 115, were chosen for separate analysis. One of these was termed the reference watershed. In this basin, standard, state-approved erosion control methods were used. The second basin was the experimental sub-watershed in which advanced and unique control techniques were studied. These two basins were to be extensively monitored and the water quality correlated with the urbanization in each basin.

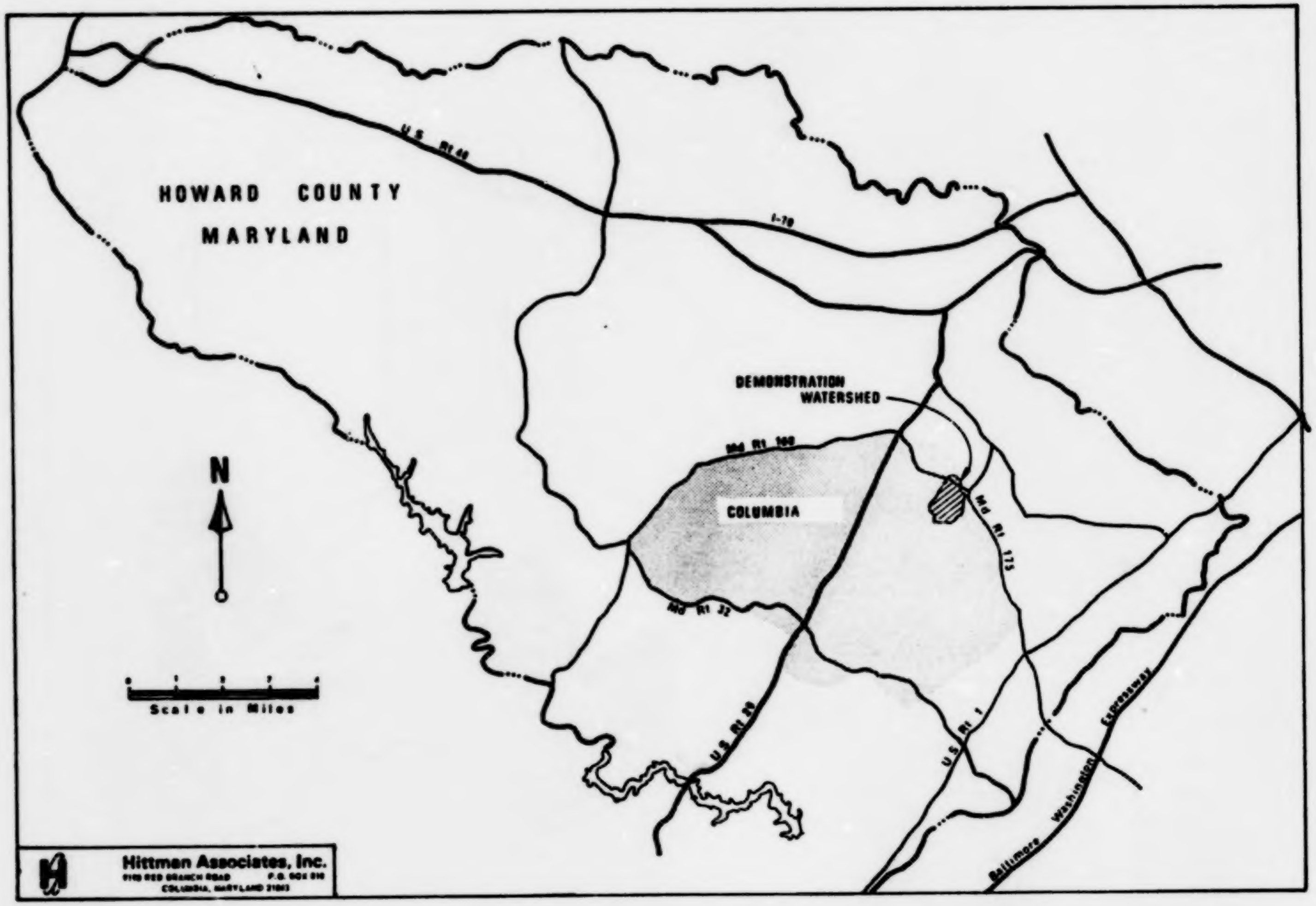
HOWARD COUNTY
MARYLAND
U.S. Rt 40
I-70
DEMONSTRATION WATERSHED
Md Rt 108
COLUMBIA
Md Rt 175
Md Rt 32
U.S. Rt 29
U.S. Rt 1
Baltimore Washington Expressway
N
0
1
2
3
4
Scale in Miles
Hittman Associates, Inc.

Exhibit 114. Geographic Location of Demonstration Area (A-17)

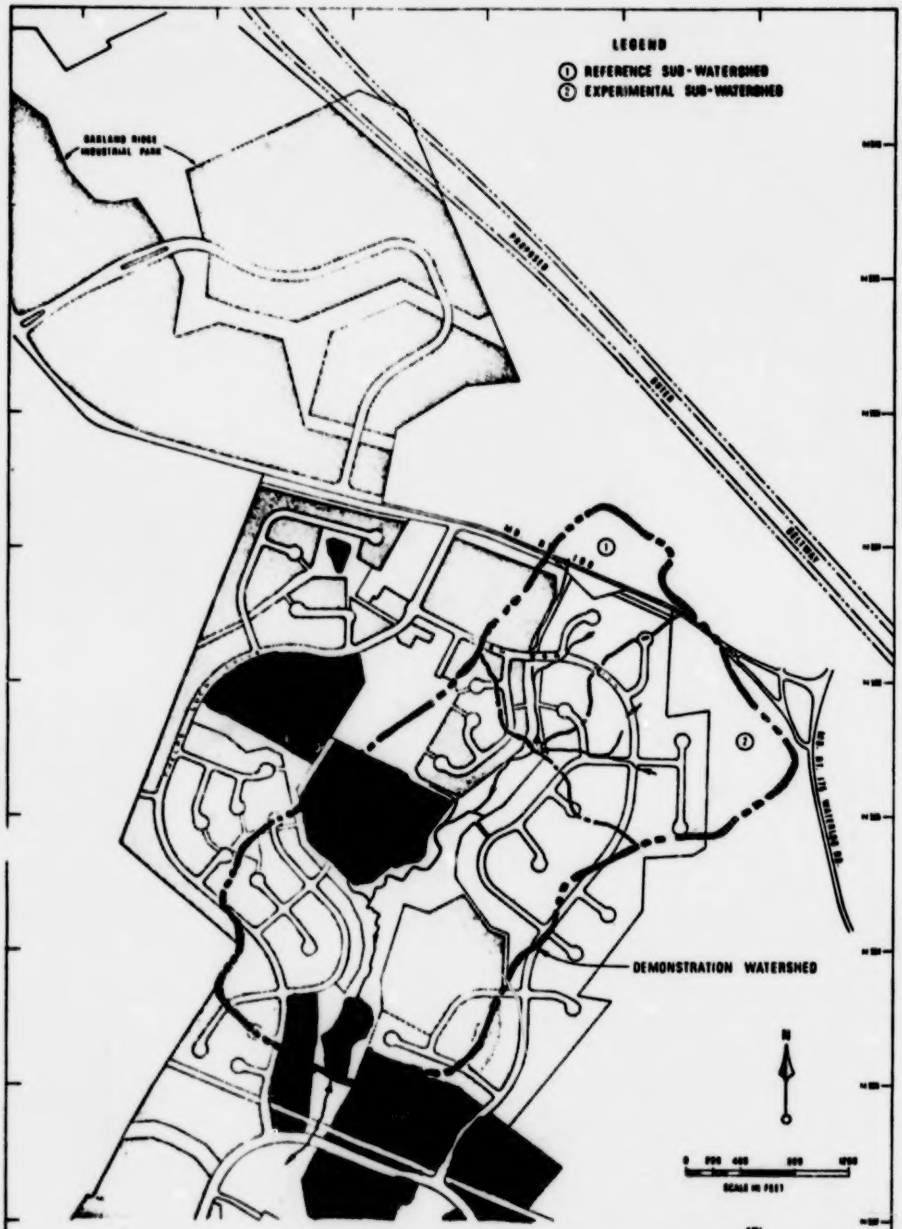
LEGEND
① REFERENCE SUB-WATERSHED
② EXPERIMENTAL SUB-WATERSHED
OAKLAND RIDGE INDUSTRIAL PARK
PROPOSED
OUTER
BELTWAY
①
②
MD. RT. 175 WATERLOO RD.
DEMONSTRATION WATERSHED
N
0 200 400 800 1200
SCALE IN FEET
Hittman Associates, Inc.

Exhibit 115. Demonstration Watershed and Subwatershed Locations, Columbia, Maryland (A-17)

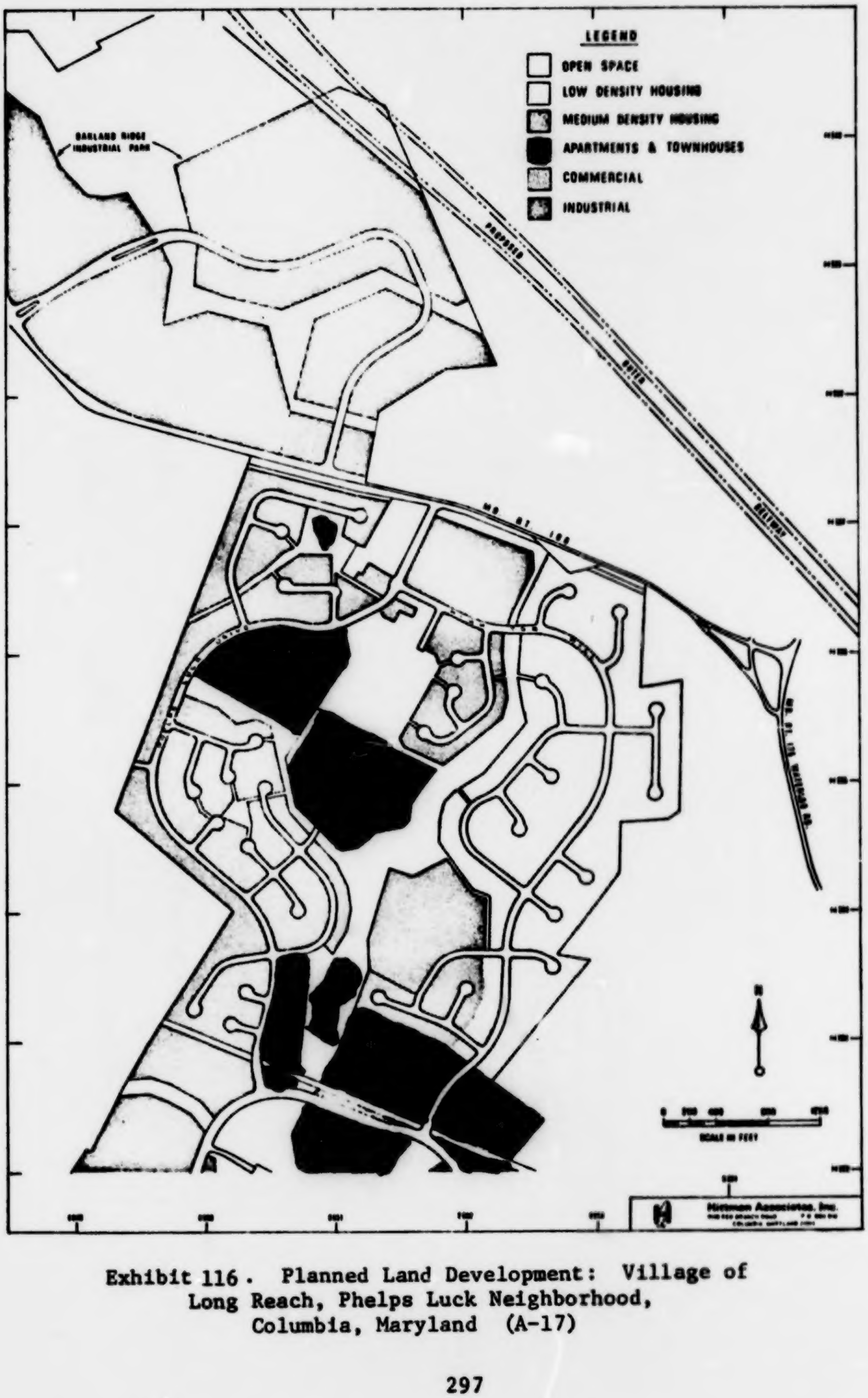
LEGEND
OPEN SPACE
LOW DENSITY HOUSING
MEDIUM DENSITY HOUSING
APARTMENTS & TOWNHOUSES
COMMERCIAL
INDUSTRIAL
OAKLAND RIDGE INDUSTRIAL PARK
PROPOSED
OUTER
BELTWAY
MD RT 108
MD RT 175 WATERLOO RD
N
0
200
400
800
1200
SCALE IN FEET
Hittman Associates, Inc.

Exhibit 116. Planned Land Development: Village of Long Reach, Phelps Luck Neighborhood, Columbia, Maryland (A-17)

Exhibit 117. PLANNED LAND DEVELOPMENT FOR THE DEMONSTRATION WATERSHED, COLUMBIA, MARYLAND (A-17)

	Demonstration Watershed (Acres)	Reference Watershed (Acres)	Experimental Watershed (Acres)
Single-family, low-density	51.7	12.5	24.2
Single-family, medium-density	53.1	6.6	----
Apartments and townhouses	19.0	----	----
Commercial	-----	----	----
Open space	17.6	4.0	0.4
Roads	22.7	2.5	3.7
Total in Columbia	164.1	25.6	28.3
Not in Columbia	26.1	9.2	16.9
Total Watershed	190.2	34.8	45.2

Time Frame -

This study was performed between 1970 and 1973. During this time urbanization was supposed to have been essentially completed.

Project Description -

Contrary to plans, construction delays resulted in development of only 31 percent of the lots in the experimental watershed. Therefore, it was difficult to determine the comparative effects of these developments. There was also a series of difficulties with the samplers which resulted in the loss of all comparative data for the two basins.

Qualitative information was obtained, however, on the changes of the biological components of streams and quantitative results for the changes in streamflow. Exhibit 118 gives the runoff characteristics of the two watersheds and Exhibits 119 and 120 give hydrographs for two separate storms during the survey.

In general the experimental watershed had less runoff per unit area than the reference subwatershed. As the study progressed, the running water (lotic) ecosystem of the stream degenerated almost completely. Its chances of natural recovery without assistance are very low. The still water (lentic) ecosystem of the newly created sediment basin was stressed due to the sediment influx, but it should be able to recover quickly. The pond will then become a valuable asset to the community.

Exhibit 118. REFERENCE AND EXPERIMENTAL SUBWATERSHED CHARACTERISTICS AS RELATED TO STORM RUNOFF PRODUCED, COLUMBIA, MARYLAND (A-17)

Characteristic	Reference Subwatershed Description	Experimental Subwatershed Description	Subwatershed with greater storm runoff per unit area as a result of characteristic
Natural ground cover	60% open field, 40% wooded	95% wooded, 5% open field	Reference
Storm sewers	Storm sewers empty into natural stream channel.	No natural stream channels, completely storm sewered.	Experimental
Development	Medium and low density housing. Approximately 20% of area devoted to school site, including parking lot.	All low density housing.	Reference
Average slope of ground	Approximately 4%	Approximately 4%	Equal

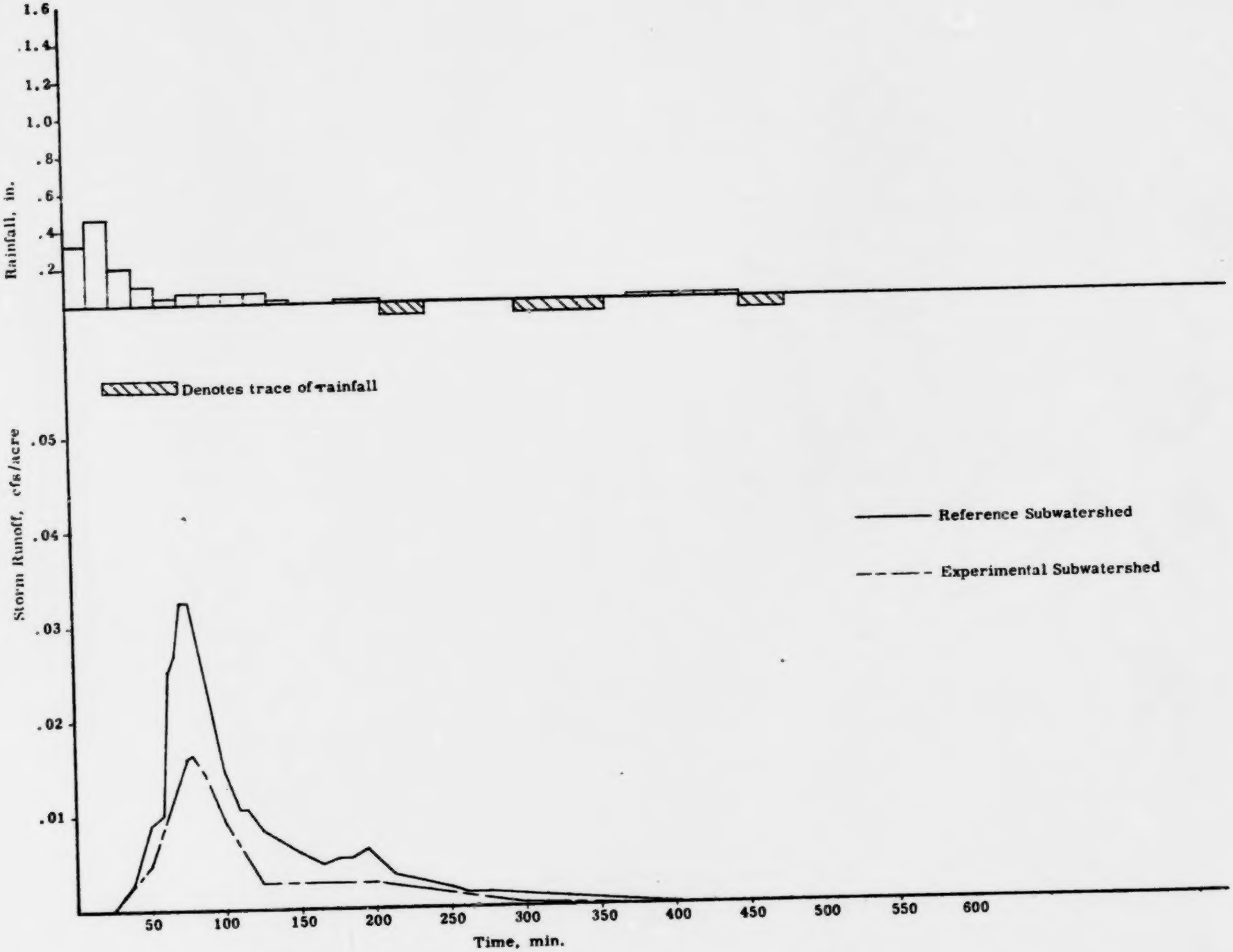

Exhibit 119. Storm Runoff Hydrograph for
Storm of July 29-30, 1971, Columbia, Maryland (A-17)

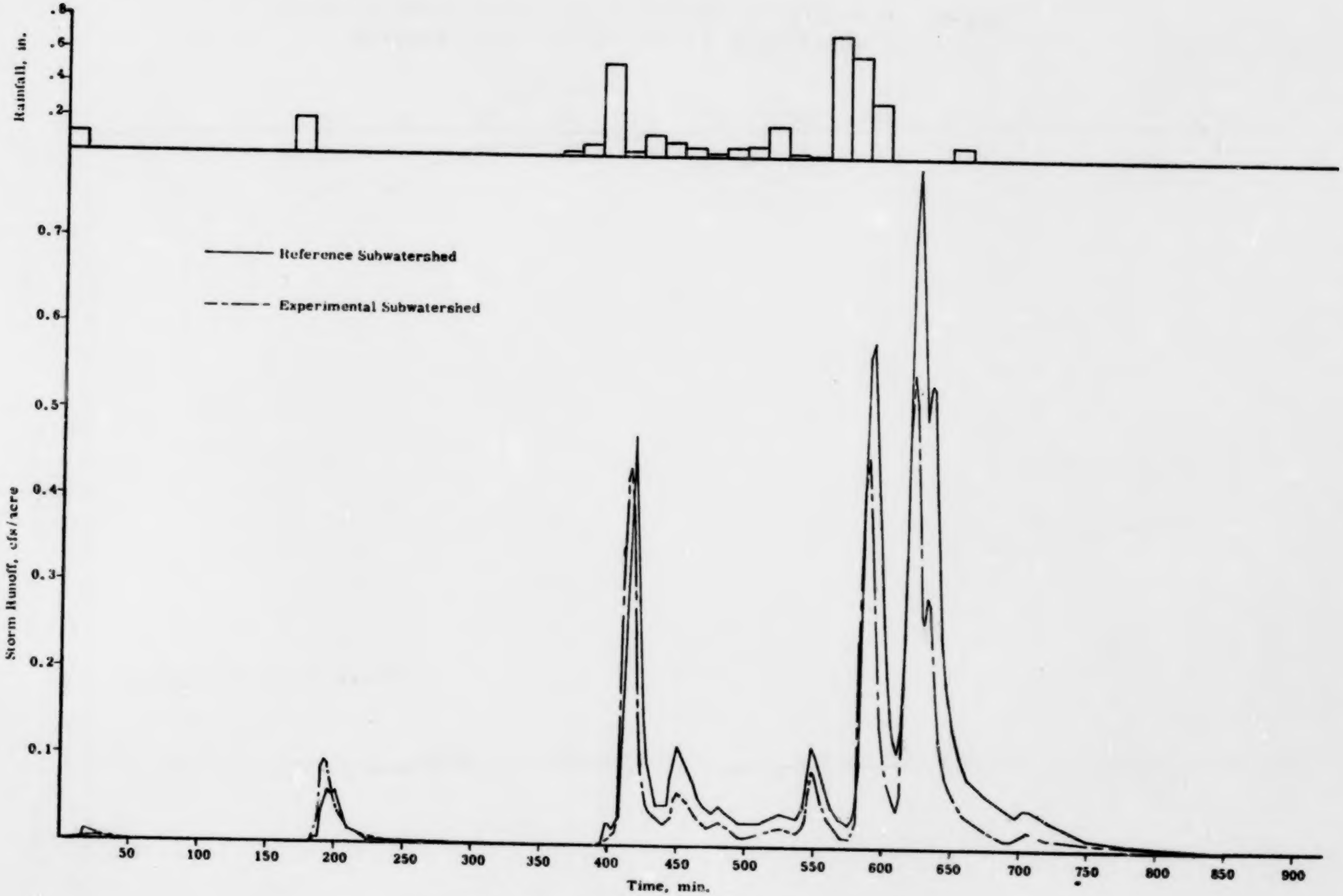

Exhibit 120. Storm Runoff Hydrograph for
Storm of August 1-2, 1971, Columbia, Maryland (A-17)

Case 18. Subdivision Development Above Gunner's Branch, Near Germantown, Montgomery County, Maryland.

Source -

At present data in raw or partially reduced form are available from EPA STORET data system (water quality) and from the Montgomery Department of Environmental Protection, Division of Resource Protection, Water Quality Control Section (precipitation and stream flow). Construction timing was obtained from the developers, U. S. Homes-Page Corp., Wheaton, Maryland.

Case Description -

This is an unusual case, in that it does not describe a study that has already been performed. Instead, its intent is to present data acquired from various sources that could be combined with other available data to produce an outstanding study of sediment loads derived from residential construction activities.

Site Location/Description -

Gunner's Branch is a small tributary to Seneca Creek in Montgomery County, Maryland. (Exhibit 121). Seneca Creek runs into the Potomac River approximately 10 miles north west of Washington, D. C. The Montgomery County Water Quality Control Section maintains a sampling station on Gunner's Branch at Clopper Road (Maryland Route 124). The drainage basin area above this point is approximately 1900 acres. This area is part of the eastern Piedmont province and consists of gently rolling hills. (Compare with the area in Case Study 42.)

Sod Type -

The soils are principally Glenelg and Manor silt loams. These are generally well draining, strongly sloping, and micaceous.

Climate/Rainfall -

The climate is typical of the mid-Atlantic coast with an average rainfall of 42 inches. Rainfall data and stream stage records taken

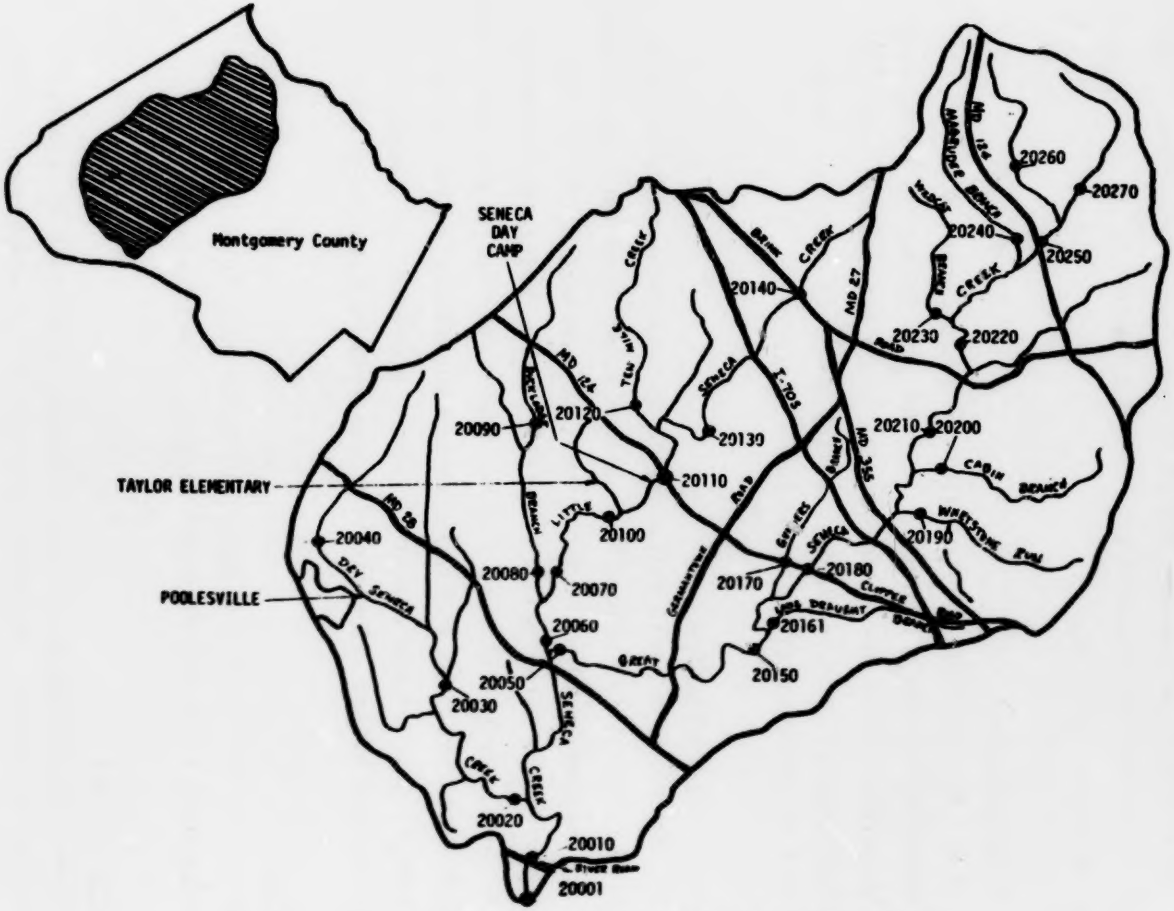
Montgomery County
SENECA DAY CAMP
TAYLOR ELEMENTARY
POOLESVILLE
MD 124
MD 28
MD 27
MD 355
I-70S
20001
20010
20020
20030
20040
20050
20060
20070
20080
20090
20100
20110
20120
20130
20140
20150
20161
20170
20180
20190
20200
20210
20220
20230
20240
20250
20260
20270
SENECA
CREEK
DRY SENECA
LITTLE
BRANCH
GREAT
TEN MILE CREEK
BRINK CREEK
GERMANTOWN ROAD
CABIN BRANCH
WHETSTONE RUN
MAGRUDER BRANCH
WILDCAT BRANCH
RIVER ROAD

Exhibit 121. Location of Sewage Treatment Plant Discharges and Stream Monitoring Stations in Region II: Seneca Creek Watershed (A-35)

during the study period are in unreduced form and are on file at the Montgomery County Water Quality section.

Time Frame -

The Montgomery County sampling station has been active since January 1971. In February 1973, U. S. Homes-Page, a local contractor, began work on a 32-acre section for a housing development. This first section remained exposed until May 1973. A second 22-acre section was opened from August 1973 to October 1973. The third and last section (32.1 acres) was developed between June 1974 and August 1974.

Sediment Control Measures -

Sediment control ponds were installed at the time of initial grading and before heavy cuts were made. Other sediment control devices such as berms, v-ditches and stone filter traps were installed as shown by the developers plans on file with Montgomery County's Construction Permit Records Division.

Data -

- Sediment load - Turbidity as ppm SiO_2 from U. S. EPA STORET,* reproduced as Exhibit 122. Stream stage and stage hydrograph are in raw (charts, etc.) form at the Montgomery County Office Building, EPA Water Quality Section.

- Construction area - data from U.S. Homes-Page Corporation:

February 1973	- May 1973	32 acres
August 1973	- October 1973	22 acres
June 1974	- August 1974	32.1 acres

- Rainfall - raw data on file at Montgomery County Office Building, EPA Water Quality Section.

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*EPA: Automated storage and retrieval system for water data.

EXHIBIT 122.

WATER QUALTIY OF GUNNER'S BRANCH AT CLOPPER ROAD, MONTOGOMERY COUNTY, MD.

Date	Time of Day	Turb ppm SiO_2	NO_2 & NO_3 mg/l	Total PO_4 mg/l	Total Coliform MPN	Fecal Coliform MPN
71/11/03	11:40	12.5	2.4	0.40	930	230
71/11/10	13:35	1.0	3.7	1.40	430	230
71/11/17	13:55	10.0	3.2	0.20	1500	230
71/12/01	10:10	4.5	2.4	0.10	9300	2300
71/12/07	09:30-R[a]	13.0	2.6	0.20	460000	9300
71/12/15	11:50	0.0	3.1	0.20	23000	2900
71/12/28	12:50	2.3	3.4	0.10	1500	230
72/01/10	10:35-R	3.0	3.3	0.20	15000	930
72/01/25	R	2.0	2.6	0.30	3900	210
72/02/10	09:50	2.0	2.9	0.31	430	230
72/02/25	10:10-R	3.0	2.4	0.10	3900	230
72/03/09	10:15	3.0	2.7	6.16	4300	2300
72/03/22	10:05-R	3.5	2.2	0.34	3900	430
72/04/05	09:55-R	1.0	2.5	0.15	930	430
72/04/19	10:30	9.0	2.7	0.24	7500	2300
72/05/02	10:00-R	4.5	2.1	0.30	9300	9300
72/05/15	11:20-R	3.0	2.5	0.25	430	430
72/05/26	10:45	2.5	2.4	0.30	2300	930
72/05/09	10:45	5.0	2.4	0.35	930	930
72/06/20	19:25	5.0	2.2	0.29	4300	930
72/06/21	22:15-R	3.0	2.3	0.29	23000	930
72/06/21	11:30	550.0	1.7	2.20	1100000	1100000
72/06/21	12:30-R	175.0	1.5	0.60	460000	240000
72/06/21	13:30-R	64.0	1.7	0.60	240000	43000
72/06/21	15:30-R	49.0	1.7	0.85	93000	23000
72/06/21	16:30-R	520.0	2.2	0.50	460000	43000
72/06/21	17:30-R	610.0	1.3	0.90	1100000	240000
72/06/21	18:30-R	1220.0	1.7	0.69	240000	240000
72/06/21	19:30-R	880.0	1.4	0.68	1100000	23000
72/06/22	14:45-R	62.0	2.4	0.25	4300	4300
72/06/22	15:35-R	60.0	3.1	0.50	23000	23000
72/06/23	10:45-R	45.0	2.1	0.43	23000	9300
72/07/11	10:00-R	2.5	2.8	0.17	4300	750
72/07/25	10:15-R	5.0	3.1	0.09	4300	2300
72/08/03	18:00-R	18.0	3.3	0.29	23000	23000
72/08/03	19:10-R	24.0	3.0	0.26	23000	9300
72/08/03	20:00-R	17.0	2.9	0.23	15000	4300
72/08/04	11:30-R	3.0	2.6	0.18	9300	4300

[a] R indicates rainfall during period

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EXHIBIT 122 (Continued)

Date	Time of Day	Turb ppm SiO_2	NO_2 & NO_3 mg/1	Total PO_4 mg/1	Total Coliform MPN	Fecal Coliform MPN
73/03/30	10:40-R	37.0	3.4	0.09	43000	930
73/04/04	12:30-R	690.0	4.1	0.08	240000-L	24000
73/04/04	13:30-R	615.0	2.2	0.29	240000-L	110000
73/04/04	14:30-R	270.0	2.9	0.05	240000-L	24000
73/04/04	15:00-R	141.0	2.4	0.10	240000-L	24000
73/04/05	10:45-R	141.0	4.6	0.25	110000	230
73/04/23	10:50	22.0	4.0	0.07	9300	1500
73/05/09	10:10-R	9.0	2.8	0.05	240000	2300
73/06/01	10:45	3.0	3.7	0.03	9300	230
73/06/25	10:15-R	1.0	4.0	0.16	930	230
73/07/13	10:05	4.0	2.5	0.03	4300	230
73/08/01	09:50-R	1.0	2.9	0.07	9300	930
73/08/15	10:30	1.0	2.6	0.08	3900	230
73/08/31	09:10	3.0	2.5	0.05	3900	280
73/09/17	10:30	1.0	3.0	0.12	3900	430
73/10/03	10:00-R	5.0	3.6	0.36	7500	930
73/10/23	10:25	29.0	3.2	0.05	230	230
73/11/08	10:30	5.0	4.2	0.08	930	930
73/11/29	10:10-R	1.0	3.3	0.28	240000-L	9300
73/12/14	10:30-R	10.0	2.6	0.16	15000	930
74/01/10	10:45-R	120.0	3.7	0.42	9300	930
74/02/01	10:20	6.0	4.4	0.15	930	36
74/02/22	11:25-R	112.0	4.0	0.37	2300	930
74/03/12	10:00-R	6.0	3.8	0.16	2300	230
74/04/02	11:20-R	10.0	3.9	0.13	9300	930
74/04/04	09:30-R	210.0	4.5	0.56	93000	23000
74/04/04	10:30-R	140.0	3.4	0.72	240000	93000
74/04/04	11:50-R	51.0	4.0	0.64	460000	39000
74/04/04	13:00-R	44.0	3.8	0.56	93000	23000
74/04/04	14:00-R	49.0	4.5	0.69	93000	43000
74/04/04	15:05-R	42.0	4.2	0.46	460000	7500
74/04/05	15:10-R	46.0	2.3	0.33	240000	9300
74/04/08	09:40	4.0	5.5	0.09	2300	930
74/04/23	10:40-R	5.0	3.7	0.12	15000	930
74/05/14	10:30	4.0	4.7	1.56	93000	7500
74/05/16	11:30	12.0	4.1	0.22	4300	930

Page 2 of 3

EXHIBIT 122 (Continued)

Date	Time of Day	Turb ppm SiO_2	NO_2 & NO_3 mg/1	Total PO_4 mg/1	Total Coliform MPN	Fecal Coliform MPN
72/08/07	10:10-R	1.0	2.6	0.14	2300	430
72/08/18	10:20-R	2.5	2.5	0.30	2300	430
72/09/06	11:00-R	4.0	2.7	0.10	430	230
72/09/14	20:25-R	245.0	2.7	0.86	460000	93000
72/09/14	22:20-R	65.0	3.0	0.50	43000	43000
72/09/20	10:00-R	2.5	3.1	0.18	750	390
72/10/05	15:40-R	0.0	3.2	0.11	4300	230
72/10/06	10:33-R	0.5	3.8	0.22	2300	430
72/10/31	10:10-R	0.0	3.2	0.80	4300	150
72/11/14	10:30-R	174.0	2.0	0.75	290000	23000
72/11/14	15:15-R	38.0	2.0	1.03	460000	9300
72/11/15	12:50-R	4.0	3.0	0.43	9300	930
72/11/17	10:15-R	3.0	3.1	0.13	2300	210
72/11/30	19:30-R	38.0	2.1	0.59	460000	43000
72/11/30	20:35-R	32.0	2.7	0.53	240000	23000
72/11/30	21:30-R	27.0	2.4	0.39	460000	43000
72/11/30	22:30-R	24.0	2.5	0.29	240000	43000
72/11/30	23:30-R	21.0	2.4	0.18	240000	23000
72/12/01	00:30-R	17.0	2.8	2.89	1100000	9300
72/12/01	09:45-R	11.0	2.4	0.07	9300	430
72/12/05	10:00	7.0	3.8	0.08	2300	93
72/12/19	10:00	7.0	3.3	2.77	4300	43
73/01/09	10:15	260.0	3.6	0.19	3900	75
73/01/26	10:00	30.0	4.4	0.07	4300	75
73/02/09	10:00-R	12.0	3.8	0.10	750	430
73/02/14	13:50-R	9.0	4.4	0.43	2300	93
73/02/14	14:45-R	5.0	4.2	0.28	230	230
73/02/14	15:45-R	9.0	4.3	0.13	2300	93
73/02/14	16:45-R	14.0	4.9	0.13	1500	150
73/02/14	17:45-R	9.0	4.3	0.35	4300	230
73/02/14	19:15-R	35.0	4.8	0.66	2300	430
73/02/14	20:15-R	64.0	4.5	0.25	15000	930
73/02/14	21:15-R	118.0	4.1	0.85	43000	230
73/02/14	22:15-R	174.0	4.0	0.15	75000	930
73/02/15	08:50-R	11.0	3.7	0.17	2100	150
73/02/15	09:40-R	18.0	3.4	0.10	4300	430
73/02/15	10:20-R	14.0	3.9	0.07	2300	43
73/02/15	12:15-R	25.0	3.4	0.17		
73/02/16	09:10-R	13.0	3.6	0.20	2300	93
73/02/27	09:35-R	5.0	3.8	0.08	930	43
73/03/15	09:20-R	5.0	3.3	0.33	750	75

Page 3 of 3

- Soil Erodibility Factor - data from Montgomery County Soil Conservation Service indicates a K factor value of approximately 0.4.

- Length and slope can be estimated from the developer's sediment control maps on file at the Montgomery County Office Building (Sediment Control Section).

- Sediment Control methods and their timing are on file at the Montgomery County Office Building (Sediment Control Section).

At present Montgomery County has cut the funding for their water quality monitoring projects. Consequently the rainfall and stream stage data will most likely remain in unreduced form for the forseeable future, unless a special need develops for this information.

APPENDIX C: EFFECTS OF DAMS AND IMPOUNDMENTS ON WATER QUALITY

General

This appendix contains summaries of six case studies containing data on turbidity effects of dam and tunnel construction projects; effects of dams on the ability of a stream to assimilate oxygen-demanding wastes, and siltation of reservoirs.

Case 19. Studies of Waste Assimilation in Impoundments and Its Effects on Water Quality

Source -

Elder, Rex A., Krenkel, Peter A., and Thackston, Edward L., "Studies of Waste Assimilation in Impoundments and Its Effects on Water Quality," Proceedings of the Specialty Conference on Current Research into the Effects of Reservoirs on Water Quality, Technical Report No. 17, Department of Environmental and Water Resource Engineering, Vanderbilt University, January 1968, pp 1-50.(A-16)

Purpose -

To investigate the effects of the construction and operation of impoundment on the waste assimilative capacity of the Coosa River.

Site Location/Description

The study took place near the Kraft Company Paper Mill on the Coosa River in Georgia.

Study Method -

A paper mill owned by the Georgia Kraft Company, located on the bank of the Coosa River, at one time discharged its waste effluent with the free flowing stream. With consturction of impoundment the mill has been forced to limit its waste-water discharge, the reason being the reduction in the waste assimilative capacity of the Coosa River. The presence of a steam electric generating plant nearby has further reduced the self-purification capacity of the stream.

The investigators monitored the daily discharge of biochemical oxygen demand (BOD) and dissolved oxygen (DO) concentrations in the Coosa River at this site.

Results -

Several observations were made concerning the effects of a stream impoundment on the ability of that stream to assimilate wastes:

a. Before water resources development BOD discharge per day = 28,000 pounds. Maximum safe temperature for required minimum DO concentration of 4 mg/l = 30°C.

   Exhibit 123 represents the oxygen sag curve for free flowing conditions.

b. After water resources development BOD discharge per day = 28,000 pounds. Maximum safe temperature for required minimum DO concentration of 4 mg/l = 15°C.

   Exhibit 124 represents the oxygen sag curve for impounded river conditions.

The quantitative effect of temperature on the waste assimilative capacity of the Coosa River is shown in Exhibit 125 by plotting the BOD load that will keep the DO contents above 4 mg/l versus the temperature of the stream water. It is clear from the curves (the curve for free flowing conditions and the curve for impounded conditions) that the impoundment of the Coosa River has contributed significantly toward the reduction of its waste assimilative capacity; the mill has to reduce its discharge of waste water going into the river from 28,000 pounds per day to less than 20,000 pounds per day to meet the requirements of the Georgia Water Quality Control Board.

In addition the following results of the studies made by other researchers are given.

1. Manczak has reported reduction in waste assimilative capacity due to impoundments in Poland. He states in his paper that the reaeration coefficients were from 1.5

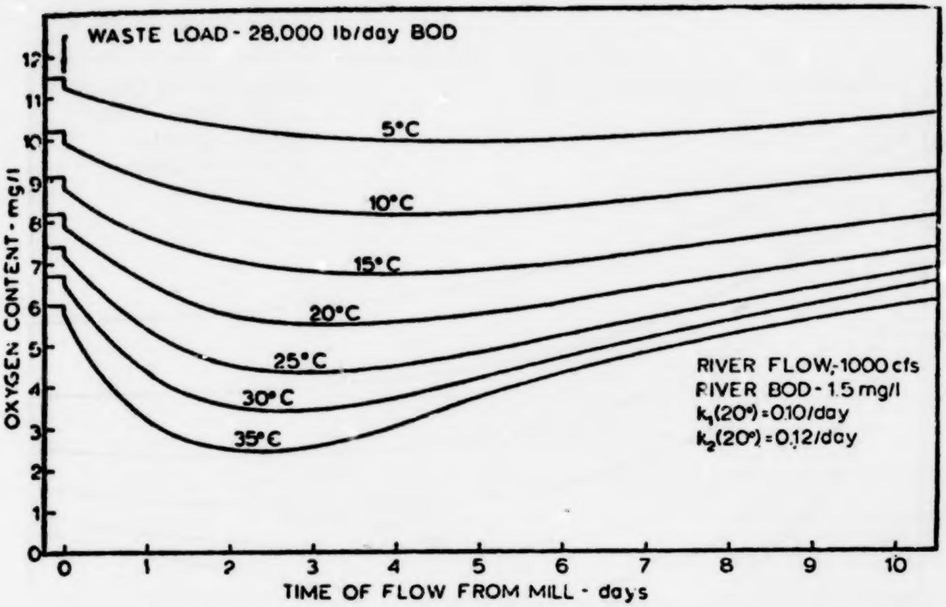

Exhibit 123. Oxygen Sag Curves-Free Flowing Condition, Coosa River, Ga. (A-16)

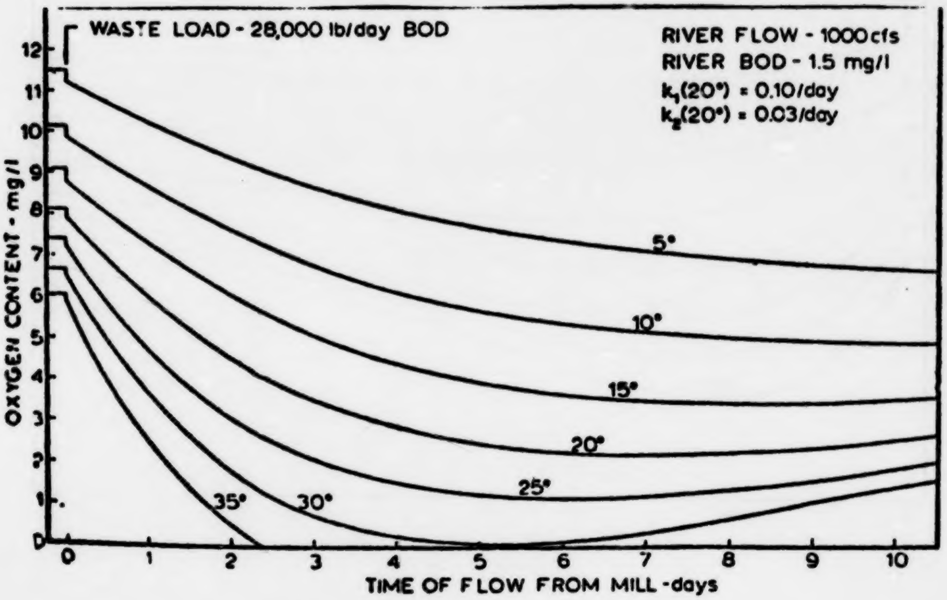

Exhibit 124. Oxygen Sag Curves-River Impounded,
Coosa River, Ga. (A-16)

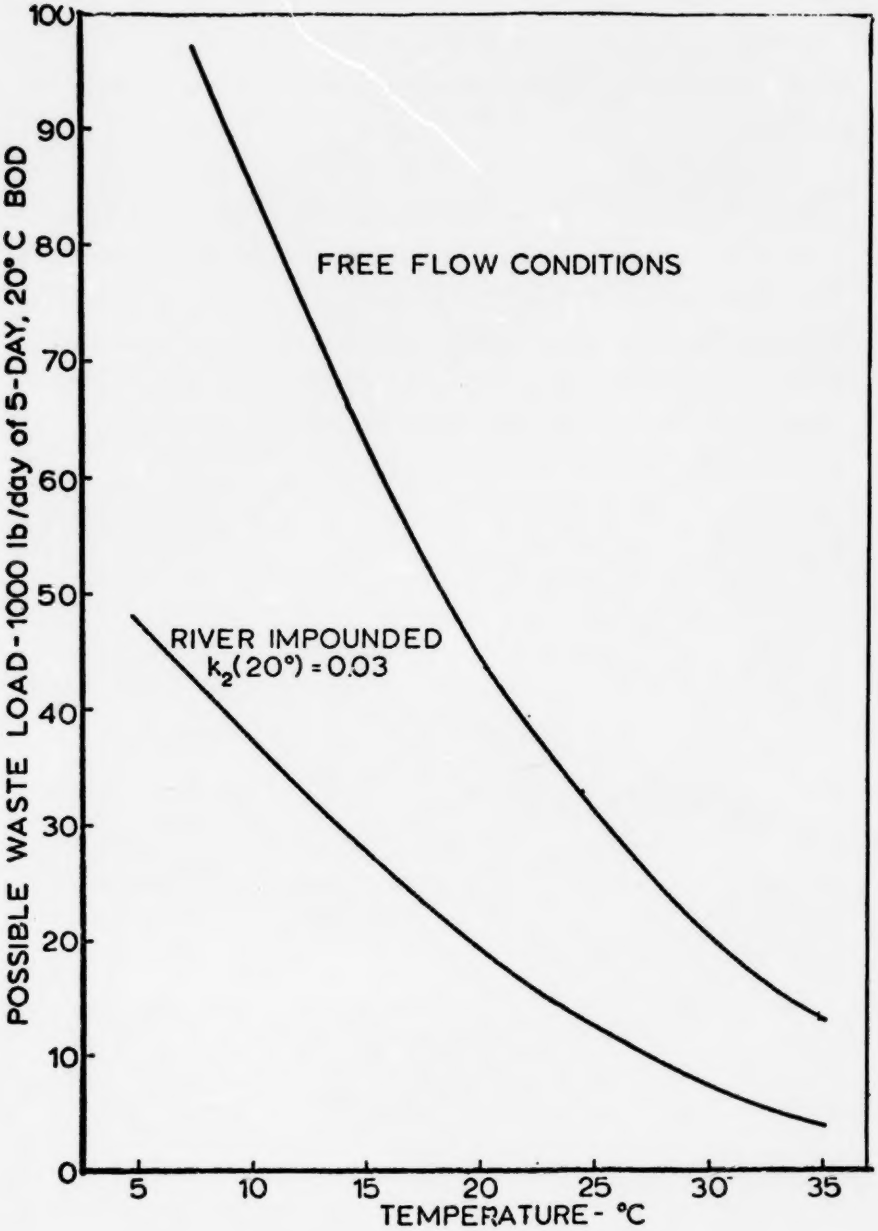

Exhibit 125. Wast Assimilative Capacity of Coosa River at Georgia Kraft Co. Mill - River Flow = 940 (A-16)

to 2.5 times higher in free flowing waters than in impoundments and that the BOD rate coefficients were 2.5 times smaller in impoundments than in the free flowing sections.

2. Bohke has stated that a dam on the Lippe River has caused reduction in the permissible load to 20 percent of that in the free-flowing river. He has pointed out a relationship between the allowable organic load in an impoundment and free flowing water which is directly proportional to the reaeration capacities and flow periods and inversely proportional to the mean depths.

Case 20. Effects of Urban Construction on Lake Barcroft

Source -

Holeman, J. N. and Geiger, A. F., Sedimentation of Lake Barcroft, Fairfax County, Virginia, SCS-TP-136, Soil Conservation Service, USDA, Washington, D. C., March 1959.(A-28)

Purpose -

The main purpose of the study was to examine the adverse effects of urban construction on Lake Barcroft and on the life of the lake by comparing the sediment yeild during the year 1957, when two-thirds of the area of the watershed had been urbanized, with the sediment yield of 1937 and by measuring the loss of capacity of the lake by aerial and land surveys.

Site Location/Description -

The lake, constructed in 1915 by Alexandria Water Company, once served as a reserve source of water supply for the city of Alexandria, Virginia. It is located in Fairfax County approximately one mile west of Bailey's Cross Roads and 8 miles from downtown Washington, D. C. In 1950 its use as a water supply reservoir was abandoned and it was subsequently purchased and used by Lake Barcroft Corporation for real estate development. A dam constructed across Holmes Run impounds water in the valleys of Holmes Run and its tributary, Tripps Run. Exhibit 126 shows the lake and its drainage area.

The following are the specifications of the dam and the reservoir:

a. Dam
   (i) Length: 400 feet
   (ii) Spillway height after raised by 5 feet in 1942: 62 ft.
b. Reservoir
   (i) Length: Length of the lake in the Holmes Run arm from the dam to the head of back water = 1.4 miles and length of the lake in the Tripps Run arm = 0.7 miles.

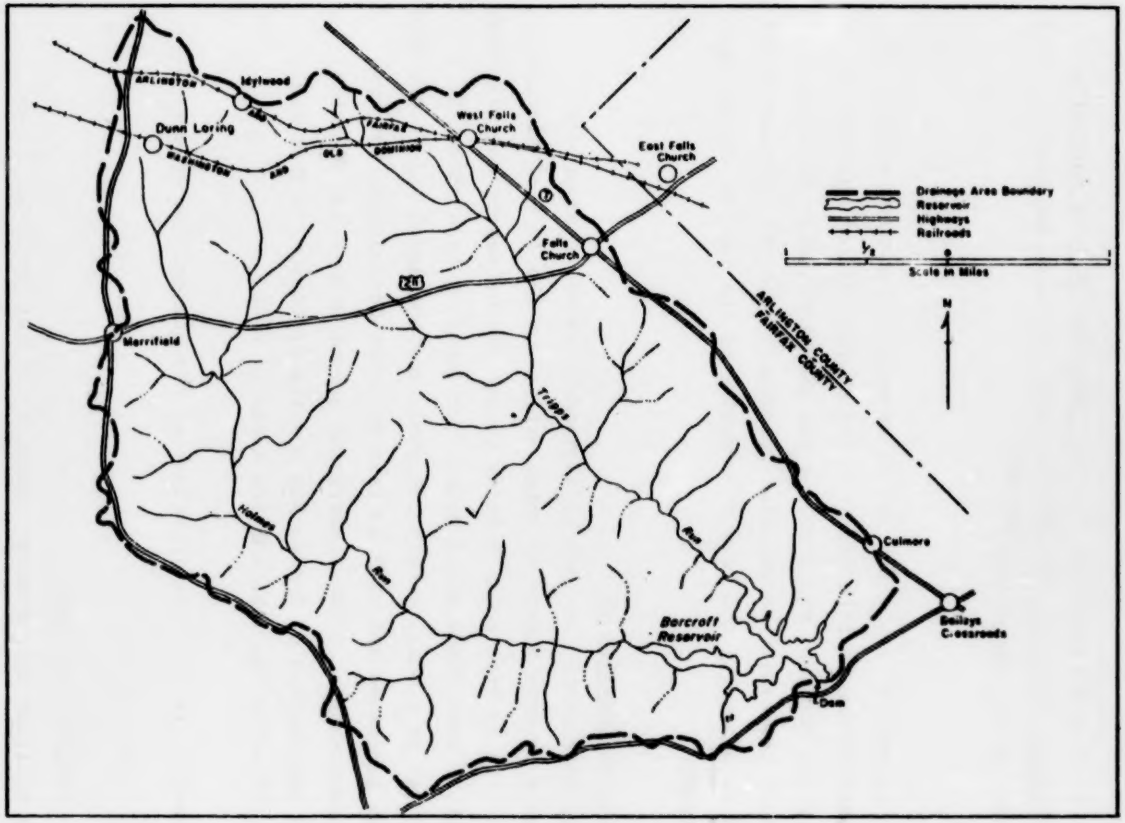
Arlington
Idylwood
and
Fairfax
West Falls Church
East Falls Church
Dunn Loring
Washington
and
Old
Dominion
7
Falls Church
29
Merrifield
Tripps
Run
Holmes
Run
Barcroft Reservoir
Culmore
Baileys Crossroads
Dam
Arlington County
Fairfax County
Drainage Area Boundary
Reservoir
Highways
Railroads
1
1/2
0
1
Scale in Miles
N

Exhibit 126. Lake Barcroft and Drainage Area (A-28)

(ii) Surface Area: The original surface area of the lake (1915) = 115.4 acres. Surface area in 1938 = 115.0 acres. Surface area in 1942 after raising spillway height by 5 feet = 135 acres. Surface area in 1957 = 129 acres

(iii) Storage Capacity:

Original (1915) = 1,847 acre-feet
In 1938 = 1,762 acre-feet
In 1942 = 2,380 acre-feet
In 1957 = 2,092 acre-feet

The drainage area of the watershed is 14.5 sq. mi. (Holmes Run = 7.6 mi^2; Tripps Run = 5.5 mi^2; and drained directly into the lower reach of the basin = 1.4 mi^2).

Topography -
Moderately rolling to hilly with average relief of 100 feet.

Soil Type -
Glenelg silt loam =53.9%
Chewacla silt loam
Wehadkee silt loam = .9%
Mixed alluvial sand
Manor silt loam
Gravelly sediment = 6.7%
Beltsville silt loam = 5.3%
Beltsville loam = 2.9%
Fairfax loam = 1.9%
Elioak silt loam = 1.8%

About 1/3 of the area, mainly in the head waters, is chlorite-muscovite schist and some thin layers of quartzite. The remaining area is granite, gneisses, and diorites. Near the lake are deposits of sand, gravel, and clay. Generally several feet of soil cover the drainage area, but bedrock is also exposed on steeper slopes near the lake.

Land Use/Ground Cover -

Exhibit 127 represents the land use changes that occurred in the watershed from 1915 to 1957. The possible changes are also extended up to 1970. From the exhibit it appears that the average rate of conversion of land from agricultural to urban use from 1937 to 1957 was 3 percent annually. Peak rate occured during 1951 and 1952 with a conversion rate of 9 percent annually. Total area urbanized from 1937 to 1957 was 9.5 square miles.

Climate/Rainfall -

Normal annual precipitation is 40.48 inches. The monthly normal ranges from 2.44 inches in February to 4.75 inches in August. (A rainfall of intensity 1 inch or more in 30 minutes occurs twice a year on the average Mean annual runoff is 17 inches (3/4th from groundwater flow and 1/4th from surface runoff or storm flow).

Study Methods -

Data were collected from the following sources:

1. Past records of the lake obtained from U. S. Department of Agriculture Soil Conservation Division Sedimentation Studies.
2. U. S. Geological Survey Department - Surface Water Supply of the United States.
3. Actual field and aerial survey of the lake for sedimentation data.

Sediment in Reservoir -

Exhibits 128 and 129 present the rates of silting of Lake Barcroft as determined by two surveys--February 1938 and August 1957.

It appears from these figures that the rate of deposition before 1938 was 3.68 acre-feet per year; total accumulation from 1915 up to 1938 was 85 acre-feet. Rate of deposition during the period from 1938 to 1957 was 10.41 acre feet per year; total accumulation for this period was 203 acre feet. It is also apparent from the figures that the rate of deposition from the rural land during the latter period is about

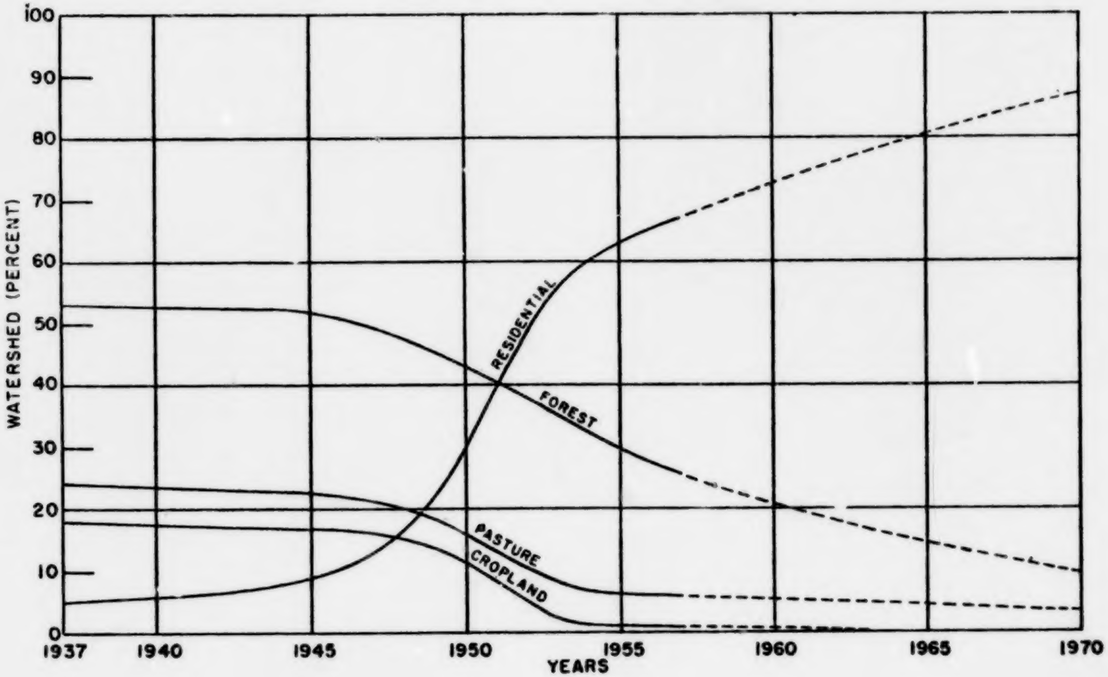

Exhibit 127. Land Use Changes of Lake Barcroft Watershed, Fairfax County, Va. (A-28)

Exhibit 128. RESERVOIR SEDIMENTATION DATA SUMMARY (A-28)

SCS-34
Jan. 1958

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

RESERVOIR SEDIMENTATION DATA SUMMARY

NAME OF RESERVOIR: Lake Barcroft
DATA SHEET NO.: 5-1

DAM			
	1. OWNER Lake Barcroft Corp.	2. RIVER Trib. of Potomac R.	3. STATE Virginia
	4. SEC. TWP. RANGE	5. NEAREST TOWN Falls Church	6. COUNTY Fairfax
	7. STREAM BED ELEV. 148 m.s.l.	8. TOP OF DAM ELEV. 211	9. SPILLWAY CREST ELEV. 210

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. SURFACE AREA ACRES	13. STORAGE ACRE-FEET	14. ACCUMULATED ACRE-FEET	15. DATE STORAGE BEGAN
	a. FLOOD CONTROL					
	b. POWER					Jan. 1915
	c. WATER SUPPLY	(1938) 205	115.4	1,847	1,847	16. DATE NORMAL OPER. BEGAN
	d. IRRIGATION					
	e. CONSERVATION					
	f. INACTIVE	(1957) 210	128.6	2,092	2,092	

17. LENGTH OF RESERVOIR 1.4 MILES; AV. WIDTH OF RESERVOIR 0.07 MILES

WATERSHED		
	18. TOTAL DRAINAGE AREA 14.5 SQ. MI.	22. MEAN ANNUAL PRECIPITATION 40 INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 14.3 SQ. MI.	23. MEAN ANNUAL RUNOFF 17 INCHES
	20. LENGTH 6.8 MILES; AV. WIDTH 2.8 MILES	24. MEAN ANNUAL RUNOFF 12,965 AC.-FT.
	21. MAX. ELEV. ± 500; MIN. ELEV. 148	25. CLIMATIC CLASSIFICATION Humid

SURVEY DATA

26. DATE OF SURVEY	27. PERIOD YEARS	28. ACCL. YEARS	29. TYPE OF SURVEY	30. NO. OF RANGES OR CONTOUR INT.	31. SURFACE AREA ACRES	32. CAPACITY ACRE-FEET	33. C/W RATIO AC-FT. PER SQ. MI.
Jan. 1915	-	-	-	-	115.4	[1] {1,847	127
Feb. 1938	23.1	23.1	Range			{2,380	
			detailed	41	115.0	1,762	122
Aug. 1957	19.5	42.6	Range	41	128.6	2,092	144

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW ACRE-FEET			36. WATER INFL. TO DATE AC.-FT.	
		a. MEAN ANNUAL	b. MAX. ANNUAL	c. PERIOD TOTAL	a. MEAN ANNUAL	b. TOTAL TO DATE

26. DATE OF SURVEY	37. PERIOD SEDIMENT DEPOSITS ACRE-FEET			38. TOTAL SED. DEPOSITS TO DATE ACRE-FEET		
	a. PERIOD TOTAL	b. AV. ANNUAL	c. PER SQ. MI.-YEAR	a. TOTAL TO DATE	b. AV. ANNUAL	c. PER SQ. MI.-YEAR
Feb. 1938	85	3.68	0.257	85	3.68	0.257
Aug. 1957	203	10.41	.728	288	6.76	.473

26. DATE OF SURVEY	39. AV. DRY WGT. LBS. PER CU. FT.	40. SED. DEP. TONS PER SQ. MI.-YR.		41. STORAGE LOSS PCT.		42. SED. INFLOW PPM	
		a. PERIOD	b. TOTAL TO DATE	a. AV. ANNUAL	b. TOT. TO DATE	a. PERIOD	b. TOT. TO DATE
Feb. 1938	[2] 60	336	336	0.20	4.60		
Aug. 1957		950	618	[1] .38	[1] 12.1		

---

[1] Based on capacity of 210-foot crest elevation.

[2] Assumed.

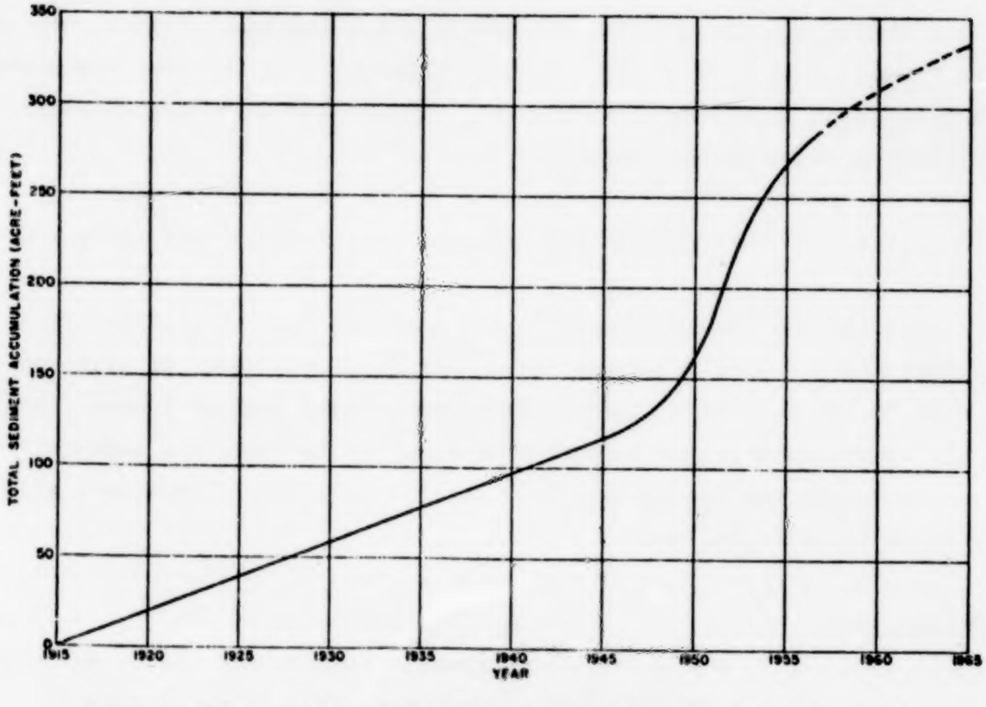

Exhibit 129. Total Sediment Accumulation in Lake Barcroft, Fairfax County, Virginia, by Year (A-28)

1/3 that of the first interval due to a large reduction in cultivated land and better land use practices. It can be concluded that the accumulation of sediment from residential construction only was 179 acre-feet.

Characteristics of Sediments -

The samples taken from the lake show the sediment to be mainly of silt and very fine sand with clay and some fine-to-medium sand. It contains mica flakes derived from the schists in the watershed. Organic matter is common throughout the lake as leaves and bits of branches and stems buried in the accumulated sediments. Exhibit 130 shows the distribution of sediment in the lake.

The density of the dried sample sediment was 49 pounds per cubic foot.

Calculations in the referenced report indicate that if one specific square mile of area goes under urbanization in one year, it will yield about 20,000 tons of sediment. With annual runoff of 17 inches, this will cause sediment concentration of about 16,500 ppm; the sediment concentration for the storm runoff portion only from this square mile will be about 66,000 ppm.

Discussion -

It is apparent from the calculated results that during the actual construction phase of urbanization, large quantities of exposed earth material and subsoil cause adverse sediment concentration in the runoff and deposition in the reservoir during heavy rainfall. This will ultimately result in the accumulation of large quantities of sediment in the reservoirs and thus decrease the usefulness and life of the reservoirs unless some preventive measures are taken to control erosion and transport of sediment.

Exhibit 130. DISTRIBUTION OF SEDIMENT IN LAKE BARCROFT

Section	Original capacity at 205-foot spillway level	Original capacity at 210-foot level	1957 sediment volume	1957 capacity loss	1957 surface area	Average sediment thickness
	Acre-feet	*Acre-feet*	*Acre-feet*	*Percent*	*Acres*	*Feet*
Tripps Run arm.....	429	573	101	17.6	30.7	2.61
Holmes Run arm.....	820	1,053	144	13.7	64.7	2.32
Lower Basin........	598	753	43	5.7	33.2	1.12
Total reservoir....	1,847	2,380	288	12.0	128.6	2.01

Case 21. Environmental Effects During Construction of Martis Creek Dam in California

Source -

Sciandrone, Joseph C. "Environmental Protection of a California Dam," Journal of Civil Engineering, ASCE, March 1974.(A-45)

Purpose -

This study records the problems related to the construction of Martis Creek Dam and makes several recommendations for erosion control during similar projects.

Site Location/Description -

The Martis Creek is a popular clear water trout stream in an undeveloped area 12 miles north of Lake Tahoe. It is a tributary to the Truckee River. The dam is an earthen dam constructed for flood control purposes and was finished in 1972. The reservoir has a capacity of 20,400 acre-ft., a length of 2 miles and shoreline of 10 miles.

Soil Type -

The soils of the valley floor were primarily glacial and alluvial deposits.

Land Use/Ground Cover -

The natural ground cover was meadow grass in the area now occupied by the reservoir. Sage brush occurs on the low hills and conifers at higher elevations.

Climate/Rainfall -

The annual precipitation is about 25 inches at the dam site and 35 inches in the upper sections of the watershed. The most important source of runoff is melting snow that accumulates during the winter. Frequent local thunderstorms occur during the summers. One storm that caused significant erosion was on July 20, 1971, during the second year of construction. Four-tenths inch of rain fell in 45 minutes, washing away significant quantities of exposed soil, increasing the stream's turbidity to 165 JTU (Jackson Turbidity Units) below the dam and to 18 JTU upstream. It took two days for the stream to return to normal conditions (0-10 JTU).

Study Method -

During the construction of Martis Dam Creek, several events were recorded which contributed to stream turbidity. This turbidity was measured in terms of JTU. Several corrective measures were employed to minimize runoff from exposed areas as well as turbidity from in-stream disturbances.

Results -

On several occasions events occurred that caused the downstream turbidity to exceed the maximum allowable concentrations (10 JTU during any consecutive 4-hour period, 20 JTU during any 1-hour period or 100 JTU at anytime). One incident was on the day water was first routed through the outlet work conduit. The outlet became blocked by debris, causing the cofferdam to overflow and wash away the embankment material, raising the turbidity to a maximum of 83 JTU before returning to normal the next day. As a result, a log boom was built and the embankment was lined with cobbles.

The primary corrective measures were the construction of temporary settling ponds by means of dikes set to intercept runoff from exposed areas, and the use of polyethylene sheets to cover the exposed soil at the crests of the dikes to provide erosion-free spillways. Other measures such as jute mulches and chemical sprays were considered but discarded. At the project end, the exposed slopes were seeded and fertilized. The steeper slopes were further mulched with a wood cellulose fiber and a diluted chemical (non-toxic) binder.

When the dam was completed and the reservoir filled, the turbidity in the pond was quite high (46 JTU) due to the silt from the cofferdam which had just been destroyed. It was decided to use a commercial flocculent to reduce the turbidity before releasing any water. Based on estimates by the manufacturer's representative, a dosage of 5 ppm was applied to the reservoir. After two weeks, the turbidity was down to 10 JTU and subsequently released. During the next week over 1000 fish died within two miles downstream. The dissolved oxygen concentration one-half mile below the dam was reported as 10.4 percent*, which is quite sufficient for fish life. It was concluded that the flocculent was the responsible agent, and that the desired dosage should have been 2 ppm.

Conclusions -

The referenced report recommends construction design to minimize soil erosion, more stringent contract specifications pertaining to seeding and ground cover (including tree) removal, and additional (beyond seeding) protection for steep slopes. It further recommends the use of plastic sheeting to protect exposed areas from heavy rainfall and spillway overflow, that dikes be designed with a freeboard of at least 3 feet above expected maximum water elevations, and the controlled use of non-toxic flocculents to remove suspended solids in ponds. One further control would be to use a sprinkler system to spray water pumped from the (turbid) sedimentation ponds into vegetated areas or areas of very permeable soil.

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*The present authors are uncertain about the interpretation of this unit.

Case 22. Construction of Dams and Tunnels on the Fryingpan-Arkansas and Teton Dam Projects*

Sources -

(a) Personal Communication: Carlson, E.J., Hydraulics Branch, Research Division of Bureau of Reclamation, Denver, Colorado, May 14, 1974.

(b) U.S. Bureau of Reclamation, Specifications, No. 6910, Paragraph 60, Supplemental Notice No. 6 (Undated).

(c) U.S. Bureau of Reclamation, "Fryingpan-Arkansas Project," Brochure, 1971.

Purpose -

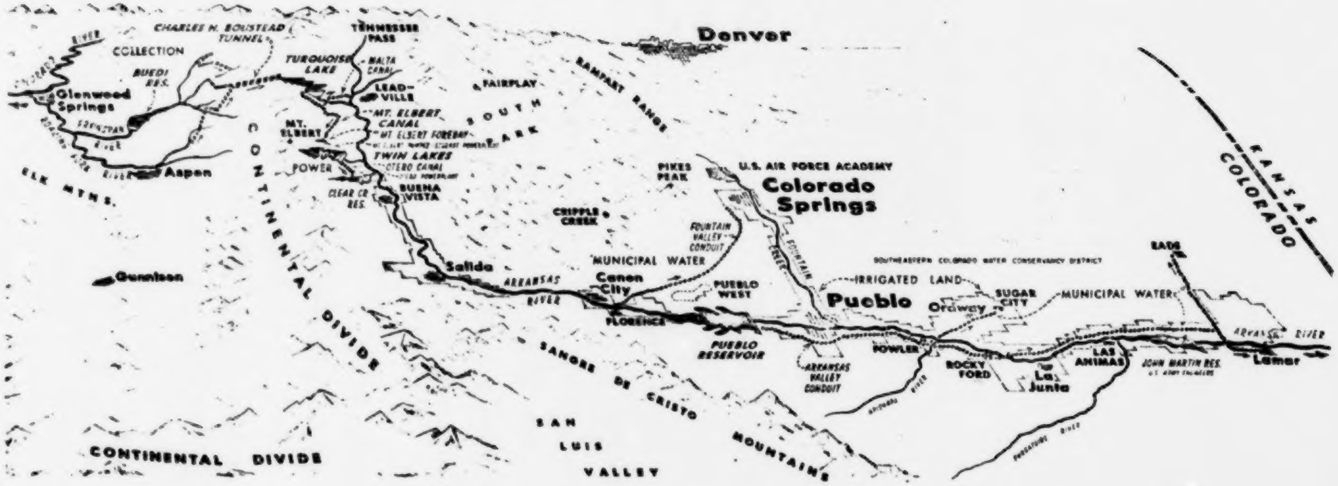
By specification, each contractor is required "to perform his construction activities by methods that will prevent entrance into the river of contaminants such as oil, refuse, sewage, cement and concrete, and to control within certain limits the turbidity of the river caused by excavation and other direct construction operations in or near the river channel." This case discusses some preliminary measurements of turbidity upstream and downstream of construction sites as indicative of compliance with these monitoring and control specifications.

Site Location/Description -

Pueblo Dam is being constructed about 6 miles west of Pueblo on the Arkansas River in Colorado. (See Exhibits 131 and 132). The earthfill structure will stand approximately 180 feet above the stream bed and will impound about 400,000 acre feet of water.

---

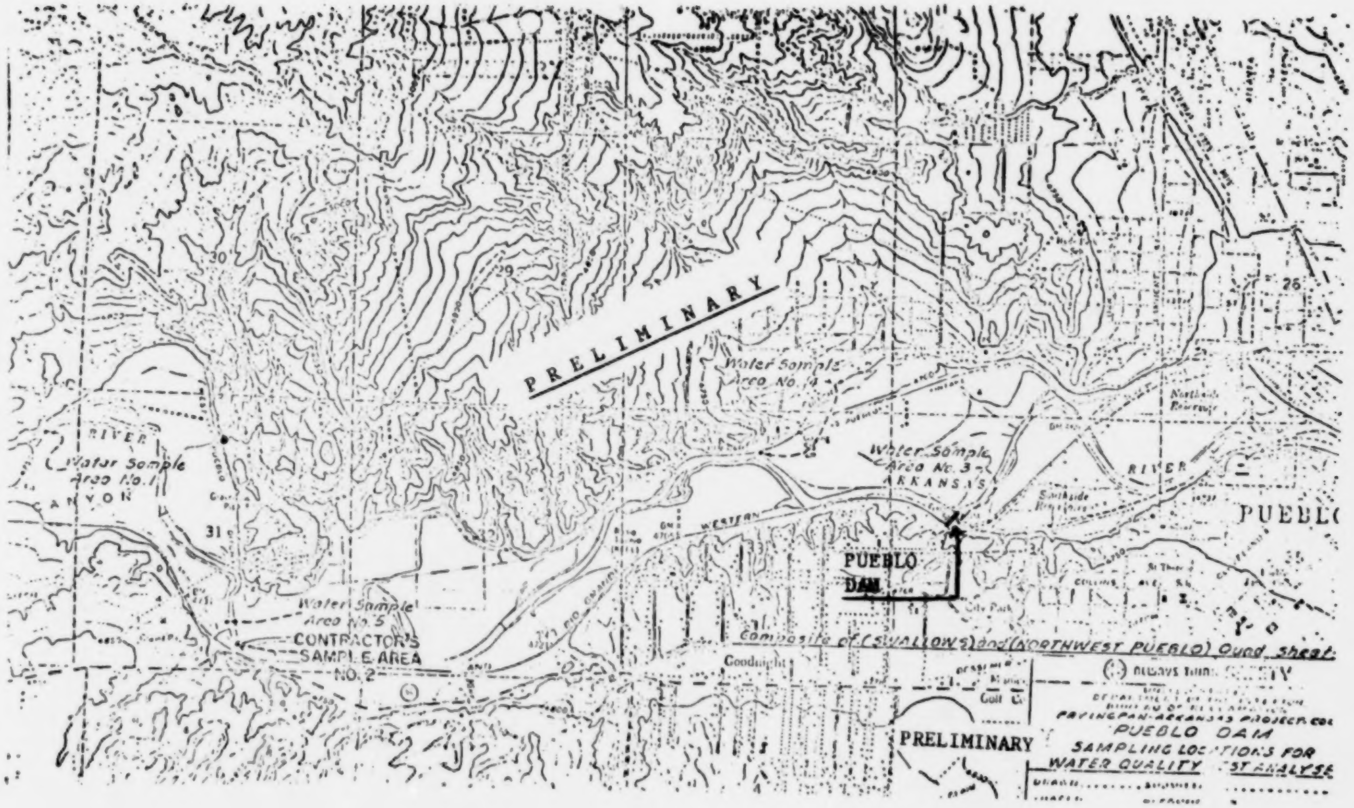
*This case pertains to the water quality effects of construction of dams, impoundments, and tunnels, as opposed to the effects of operating these facilities. (The latter subject is addressed in other case studies of this section.) It pertains also to measures for controlling water pollution from these types of construction.


Denver
CHARLES H. BOUSTEAD TUNNEL
COLLECTION
RUEDI RES.
COLORADO RIVER
Glenwood Springs
FRYINGPAN RIVER
ROARING FORK RIVER
Aspen
ELK MTNS.
TENNESSEE PASS
TURQUOISE LAKE
MALTA CANAL
LEAD-VILLE
FAIRPLAY
MT. ELBERT
MT. ELBERT CANAL
MT. ELBERT FOREBAY
TWIN LAKES
OTERO CANAL
POWER
CLEAR CR. RES.
BUENA VISTA
SOUTH PARK
RAMPART RANGE
CONTINENTAL DIVIDE
Gunnison
CRIPPLE CREEK
Salida
ARKANSAS RIVER
MUNICIPAL WATER
Canon City
FLORENCE
PIKES PEAK
U.S. AIR FORCE ACADEMY
Colorado Springs
FOUNTAIN VALLEY CONDUIT
FOUNTAIN CREEK
PUEBLO WEST
PUEBLO RESERVOIR
SANGRE DE CRISTO MOUNTAINS
SAN LUIS VALLEY
CONTINENTAL DIVIDE
SOUTHEASTERN COLORADO WATER CONSERVANCY DISTRICT
IRRIGATED LAND
Pueblo
Ordway
SUGAR CITY
MUNICIPAL WATER
FOWLER
ARKANSAS VALLEY CONDUIT
ROCKY FORD
La Junta
LAS ANIMAS
JOHN MARTIN RES.
EADS
ARKANSAS RIVER
Lamar
KANSAS
COLORADO

Source: Reference (c)

Exhibit 131. General Location of Major Facilities in the Fryingpan-Arkansas Project

Reproduced from best available copy.


PRELIMINARY
Water Sample Area No. 4
Water Sample Area No. 3
ARKANSAS
RIVER
PUEBLO
PUEBLO DAM
Water Sample Area No. 1
RIVER
CANYON
Water Sample Area No. 5
CONTRACTOR'S SAMPLE AREA NO. 2
Goodnight
Composite of (SWALLOWS) and (NORTHWEST PUEBLO) Quad Sheets
PRELIMINARY
FRYINGPAN-ARKANSAS PROJECT, COLO.
PUEBLO DAM
SAMPLING LOCATIONS FOR
WATER QUALITY TEST ANALYSES

Source: Reference (a)

Exhibit 132. Map of Area Near Pueblo Dam Construction Site

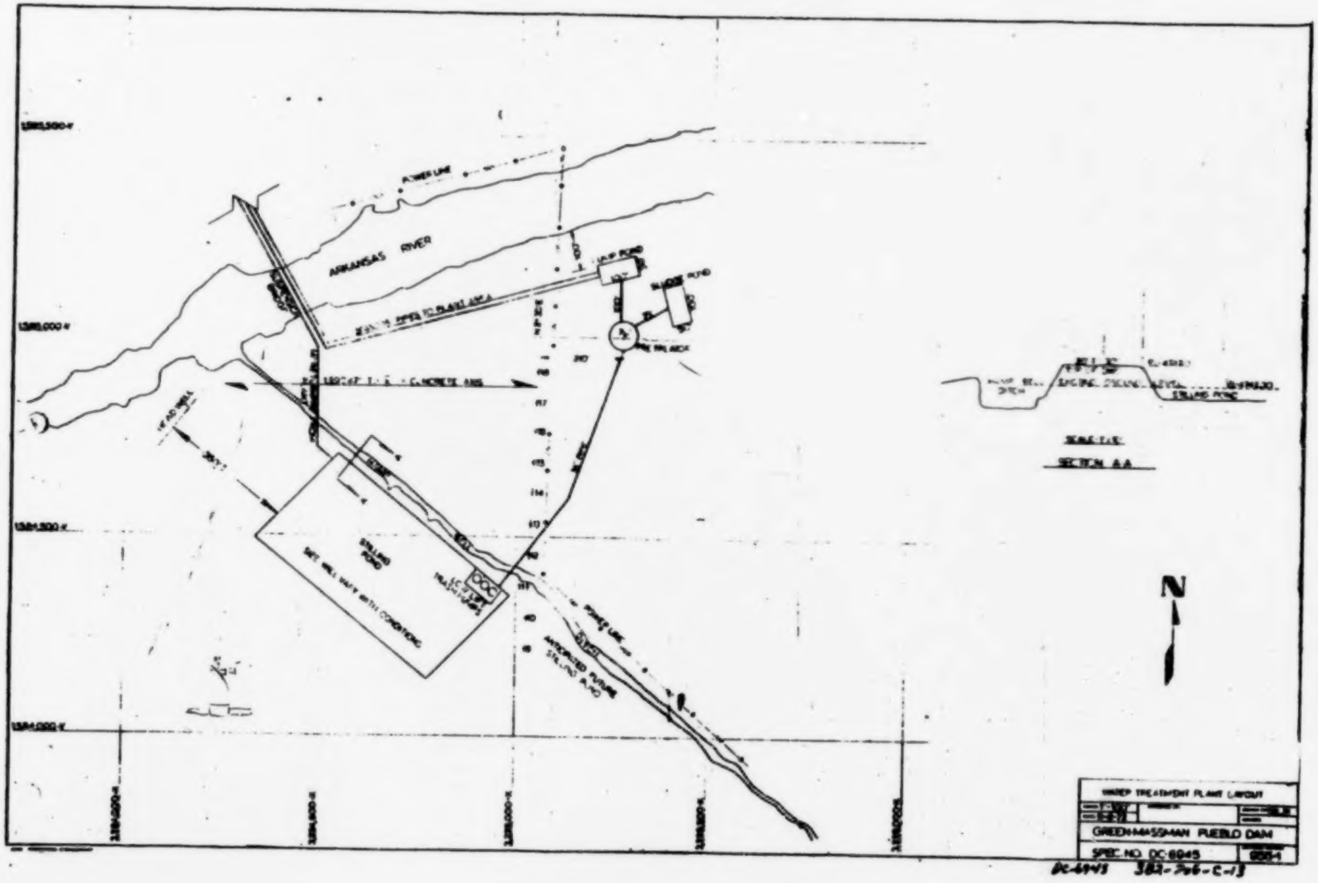
The Teton Dam Site, located on the Teton River in Idaho, contains a damsite, two diversion channels at the damsite, and a diversion channel at the borrow area.

The Hunter Construction site is located near the confluence of Chapman and Sawyer Creeks in the collection area of the Fryingpan-Arkansas Project.

Various control measures were incorporated at each of these sites. The construction area of the Pueblo Dam is a closed system which recycles the water used in the construction processes (gravel washing, concrete mixing and washing, etc). This system is shown in Exhibit 133. Pretreatment is provided by a Dorr-Oliver Pretreator.

The control methods used for the Teton Dam project are similar to those used at the Pueblo site. The Dorr-Oliver Pretreator was also to be used at the Teton site. However, because of delayed delivery, a 40' x 160' settling basin was established temporarily by driving steel sheet pilings vertically into the ground near the river at the downstream end of the construction site. Flocculating agents were then added and clear water was discharged into the river. Flocculating agents were also added to the turbid water of new channels. The channel was also moved away from the borrow area to guard against any sediment runoff from that area.

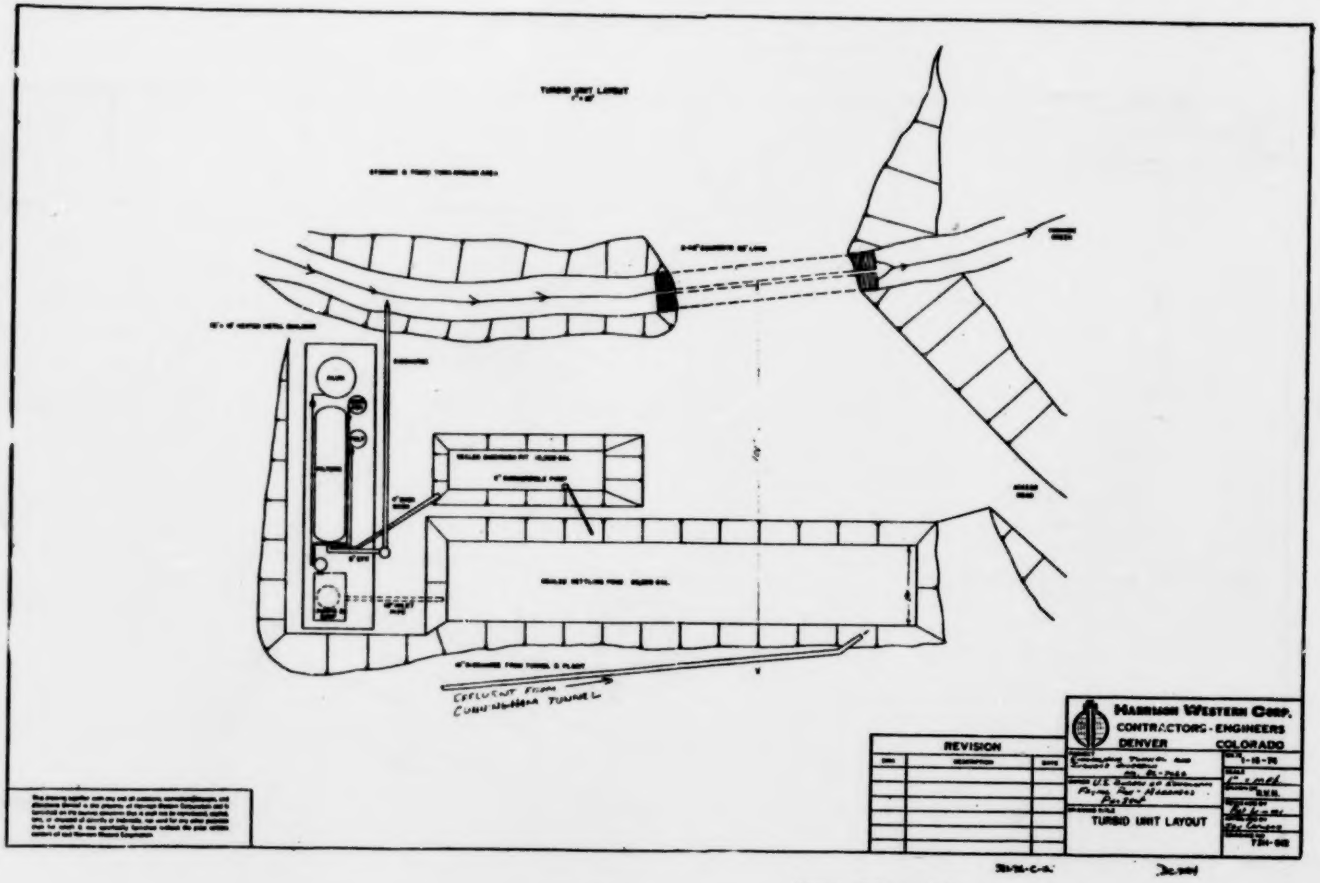
The turbidity control measures being used at the Hunter Tunnel are similar to those being used at the Cunningham Tunnel as shown in Exhibit 134. However, instead of having the filtering system which is outlined for the Cunningham Tunnel, the Hunter tunnel makes use of a larger settling basin which is possible because there is more available area at this site. Flocculants are added to the settling basin.


POWER LINE
ARKANSAS RIVER
STILLING POND
SIZE WILL VARY WITH CONDITIONS
POWER LINE
ANTICIPATED FUTURE STILLING POND
SECTION A-A
N
WATER TREATMENT PLANT LAYOUT
GREEN-MASSMAN PUEBLO DAM
SPEC. NO. DC-6945
DC-6945 383-706-C-13

Source: Reference (a)

WATER TREATMENT PLANT LAYOUT

Exhibit 133. Pollution Control Facilities at Pueblo Dam Construction Area


HARRISON WESTERN CORP.
CONTRACTORS - ENGINEERS
DENVER COLORADO
REVISION
TURBID UNIT LAYOUT
EFFLUENT FROM
CUNNINGHAM TUNNEL

Source: Reference (a)

TURBIDITY UNIT LAYOUT

Exhibit 134. Pollution Control Facilities At Cunningham Tunnel Construction Area

Climate/Rainfall -

The annual precipitation in the Fryingpan-Arkansas area is 11.6 inches. The maximum temperature is 114°F while the minimum temperature recorded is -32°F and the mean temperature is 52°F. The growing season is 163 days.

Topography -

The drainage area near Pueblo,Colorado is 4,686 square miles. The average annual runoff is 519,100 acre feet. Exhibit 132 gives a general idea of the relief of the area.

Study Methods -

Each site had several monitoring stations:

Pueblo Dam Area Use	Station #	Location in Relation to Construction
Borrow Pit (for construction material-gravel	1	2 1/2 mi. upstream (or 1/3 mi./downstream of Canyon Dam Rock Barrier)
aggregates, soil	2	7 mi. upstream
fill	3	Immed. downstream
	4	3/4 mi. upstream
Temporary and	5	2 1/2 mi. upstream
Permanent	6	4 mi. upstream
channel realignment	7	5 mi. upstream
for borrow and stream straightening	8	6 mi. upstream
Teton Dam		
Temporary and	1	2000 feet upstream
permanent channel realignment, general construction	2	3300 feet downstream
Hunter Tunnel		
Above outlet portal	1	NA
below Settling Ponds	2	NA
confluence of Chapman and Sawyer Creeks	3	NA

At each of these sites, turbidity readings were made with a Hach 2100 colormeter/turbidmeter twice daily. These readings were made in JTU (Jackson Turbidity Units) or FTU (Formazin Turbidity Units). At the Pueblo Dam area, turbidity readings were compared with results of weighed filtered residue which generated suspended sediment load figures in ppm's. These results did not correlate [illegible]

Parameters Measured -

- Turbidity

Results -

Continuous measurements of turbidity were made upstream and downstream of each construction site, in some cases at several locations. Results are in a very preliminary stage at this time. Some of the partially processed data from three construction sites are presented below as an example to indicate the nature of the information being obtained.

Turbidity readings at one station upstream and one station downstream of the Pueblo Dam construction site are shown in Exhibit 135. Exhibit 136 is an example of turbidities at three stations at the Pueblo site, plotted for the year 1972.

Turbidity readings above and below the settling pond at the Hunter Tunnel construction area are shown for the year 1972 in Exhibit 137. Turbidities upstream and downstream of the Teton Dam construction area are shown for a portion of the year 1972 in Exhibit 138. The occurrence of certain major construction events is indicated on this graph.

It is assumed that the data contained in these exhibits can be correlated in time with phases of construction and meterological events when project construction records become available. This correlation was not undertaken in the present study, since the parameter measured--turbidity--is not of primary value in the development of loading functions.

Exhibit 135. TURBIDITY READINGS UPSTREAM AND DOWNSTREAM FROM PUEBLO DAM CONSTRUCTION AREA

CONTRACTOR-STATIONS

DATE			TIME	Turbidimeter Reading (FTU'S) STA. NO. 3	STA. NO. 2
02	02	73	16:15		6.0
02	12		16:45	14.9	
02	15		08 30	5.5	
02	15		09:00		7.5
02	16		08:45	4.3	
02	16		0905		5.3
02	19		0945	5.5	
02	19		1020		6.3
02	19		1610	4.1	
02	19		1617		6.2
02	20		0945	14.0	
02	20		1130		17.0
02	20		1610	5.5	
02	20		1625		6.5
02	21		0815	6.5	
02	21		0825		6.9
02	21		1400	5.5	
02	21		1440		6.5
02	22		0945	14.9	
02	22		0950		6.5

Page 1 of 2

Exhibit 135. (Continued)

DATE	TIME	Turbidimeter Reading (JTU'S)	
		STA. NO. 3	STA. NO. 2
02 22 73	1600	14.9	
02 22	1615		14.0
02 23	1815	6.5	
02 23	0845		5.5
02 26	1600	3.0	
02 26	1610		6.0
02 27	0850	4.5	
02 27	0905		6.3
02 28	0810	6.0	
02 28	0840		4.5
02 28	1550	4.4	
02 28	1630		4.7
03 01	0915	3.5	
03 01	0930		7.5
03 02	1015	6.4	
03 02	1030		7.7
03 02	1615	4.5	
03 02	1630		6 9
03 05	0815	4.9	
03 05	0830		6.9
03 05 73	1630	3.4	
03 05	1646		5.0
03 06	0810	3.6	
03 06	0820		9.9
03 06	1630	3.4	
03 06	1640		4.5
03 07	0830	4.0	
03 07	0840		3.7
03 07	1620	2.5	
03 07	1630		3.0
03 08	1600	3.5	
03 08	1615		3.8
03 09	0830	4.7	
03 09	0855		4.9
03 09	1600	4.9	
03 09	1615		4.1
03 12	1430	3.5	
03 12	1444		34.8
03 13	0830	3.5	
03 13	0840		15.7

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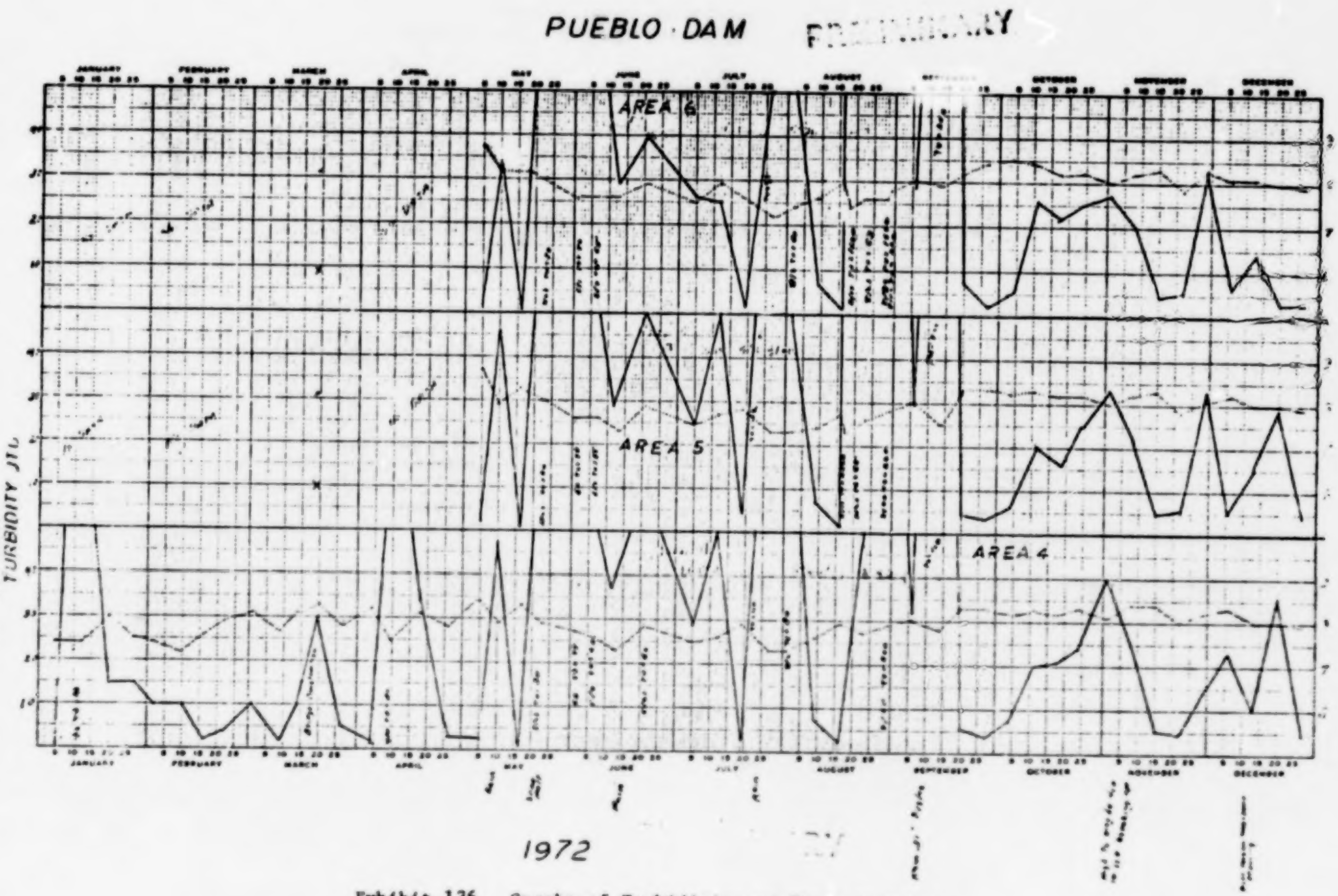


Exhibit 136. Graphs of Turbidities at Three Stations Near Pueblo Dam Construction Area During 1972

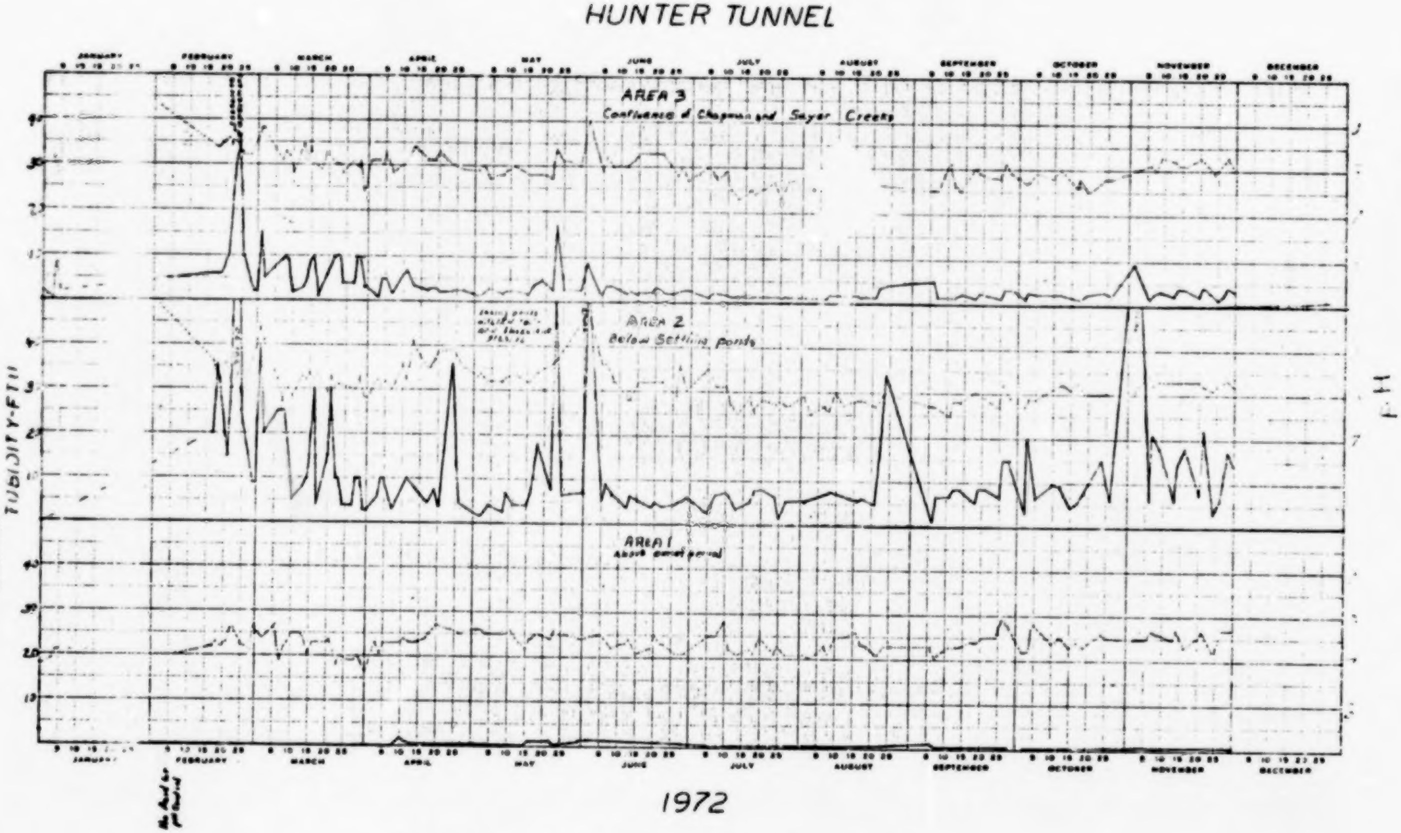
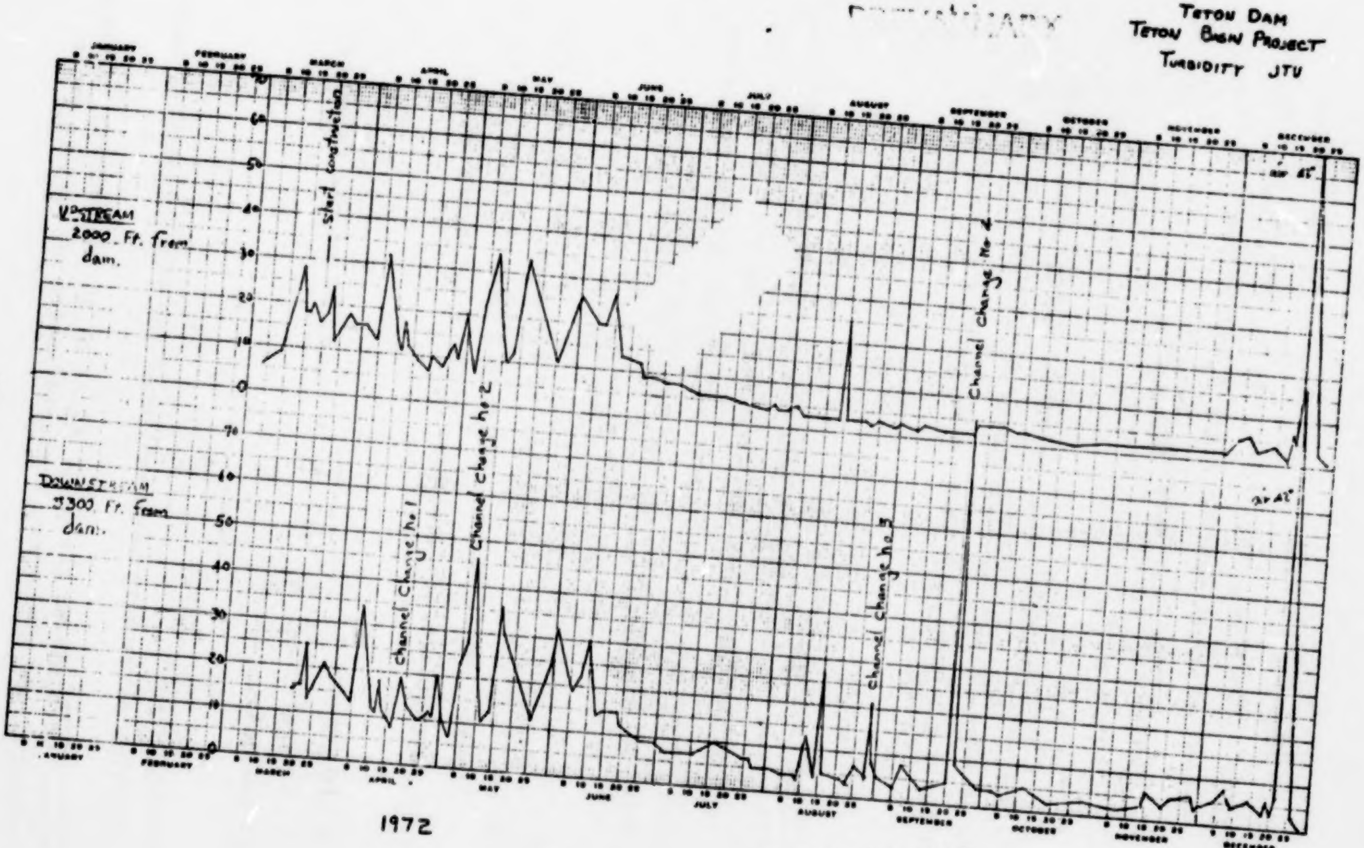


Exhibit 137. Turbidities at Three Locations Near Hunter Tunnel Construction Site



PRELIMINARY

Exhibit 138. Turbidities Upstream and Downstream
of Teton Dam Construction Project

Case 23. Behavior of Water in a Southwestern Impoundment - Lake Thunderbird*

Source -

Edwin H. Klehr, "Behavior of Water in a Southwestern Impoundment - Lake Thunderbird." Technical completion report, OWRR Project No. A-013-OKLA. School of Civil Engineering and Environmental Science, University of Oklahoma, Norman, Oklahoma.(A-31)

Purpose -

To monitor physical, chemical, and biological water quality parameters; and to develop a physical sediment-water mixing model to correlate the quality of the lake water with the characteristics of its watershed.

Site Location/Description -

Exhibit 139 shows the location of Lake Thunderbird and its watershed situated in Oklahoma and Cleveland Counties. The watershed is 256 square miles in area. This lake acts as a major source of surface water supply for Norman, Midwest, and Del city.

Soil Types -

It is estimated that about 65 percent of the area is underlain by Garber-Wellington Sandstone at shallow to moderate depths. The remaining 35 percent area is Hennessey Shale at moderate depth.

Climate/Rainfall -

Rainfall averages 33.4 in./yr. Only about 11% of the rainwater reaches the lake.

Parameters Measured -

The following parameters were monitored for the Thunderbird Lake.

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*This case pertains to the performance of an impoundment in changing the chemical and biological characteristics of surface water.

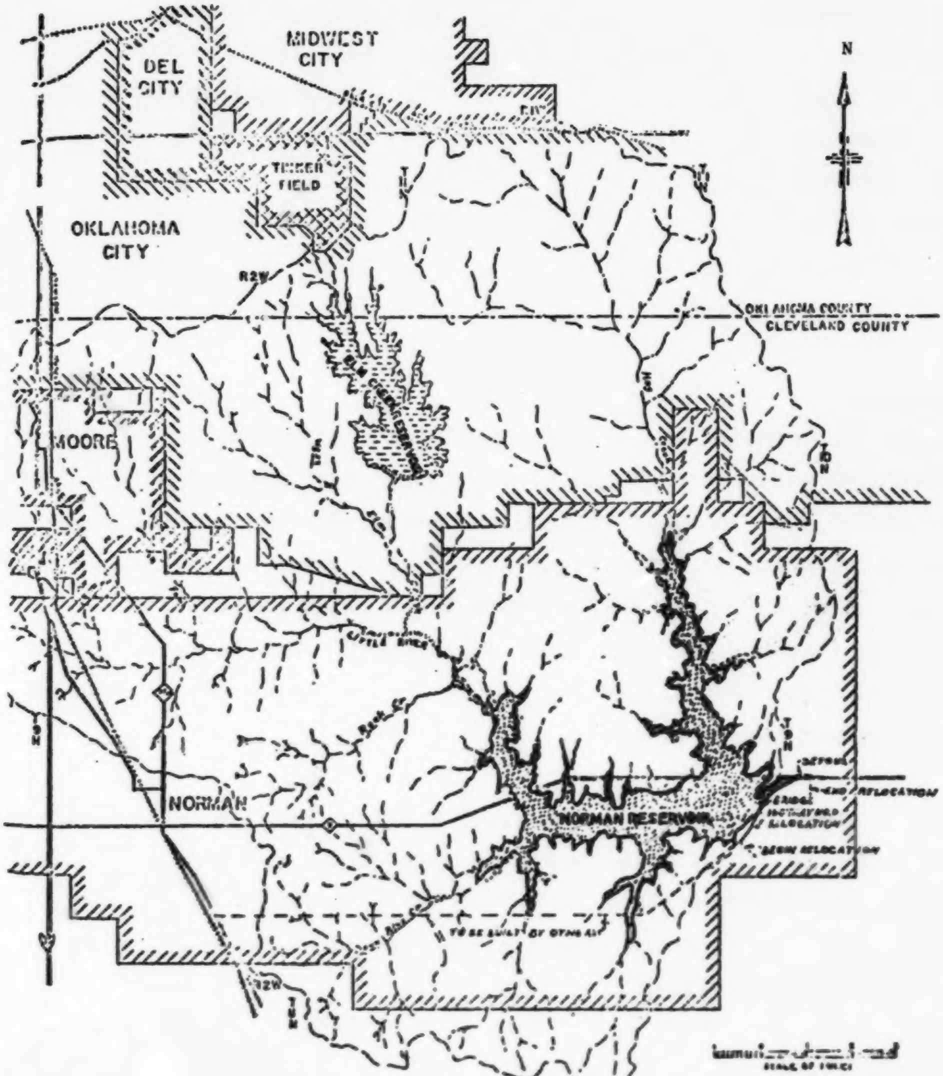
MIDWEST CITY
DEL CITY
TINKER FIELD
OKLAHOMA CITY
N
R2W
OKLAHOMA COUNTY
CLEVELAND COUNTY
MOORE
NORMAN
NORMAN RESERVOIR
RELOCATION
RELOCATION
TO BE BUILT BY OTHERS
R2W
R1W
SCALE OF MILES

Exhibit 139. Watershed at Norman Reservoir (Lake Thunderbird)$^{(A-31)}$

Exhibit 140 shows the locations of the sampling stations. Some parameters were also measured for the watershed's main streams.

1. pH
2. Turbidity and particle size
3. Total dissolved solida
4. Sulphates
5. Iron
6. Manganese
7. Ammonia
8. Nitrate
9. Nitrite
10. Orthophosphate
11. Total phosphate
12. Chlorine
13. Alkalinity
14. Total Hardness
15. Calcium Hardness
16. Dissolved Oxygen
17. Biological Oxygen Demand
18. Chemical Oxygen Demand
19. Sodium
20. Water - Temperature
21. Bacteria
22. Coliform

Results-

A laboratory model was studied involving the percolation of aerated distilled water through small columns (1" x 5" and 5 3/4" x 5") of watershed soil in order to simulate watershed runoff. The percolated water collected in a container served as a model of the lake itself. Using total dissolved solids as an index of comparison between the results obtained from the field measurements and the lab study, it was concluded that laboratory simulation of watershed and lake or impoundment can be possible.

The results of chemical analyses of the lake and its tributaries are given in Exhibits 141 and 142. Results of a biological analysis at one location are given in Exhibit 143. Exhibit 144 gives the summary of the particle size distribution of sediment at various locations in the lake.

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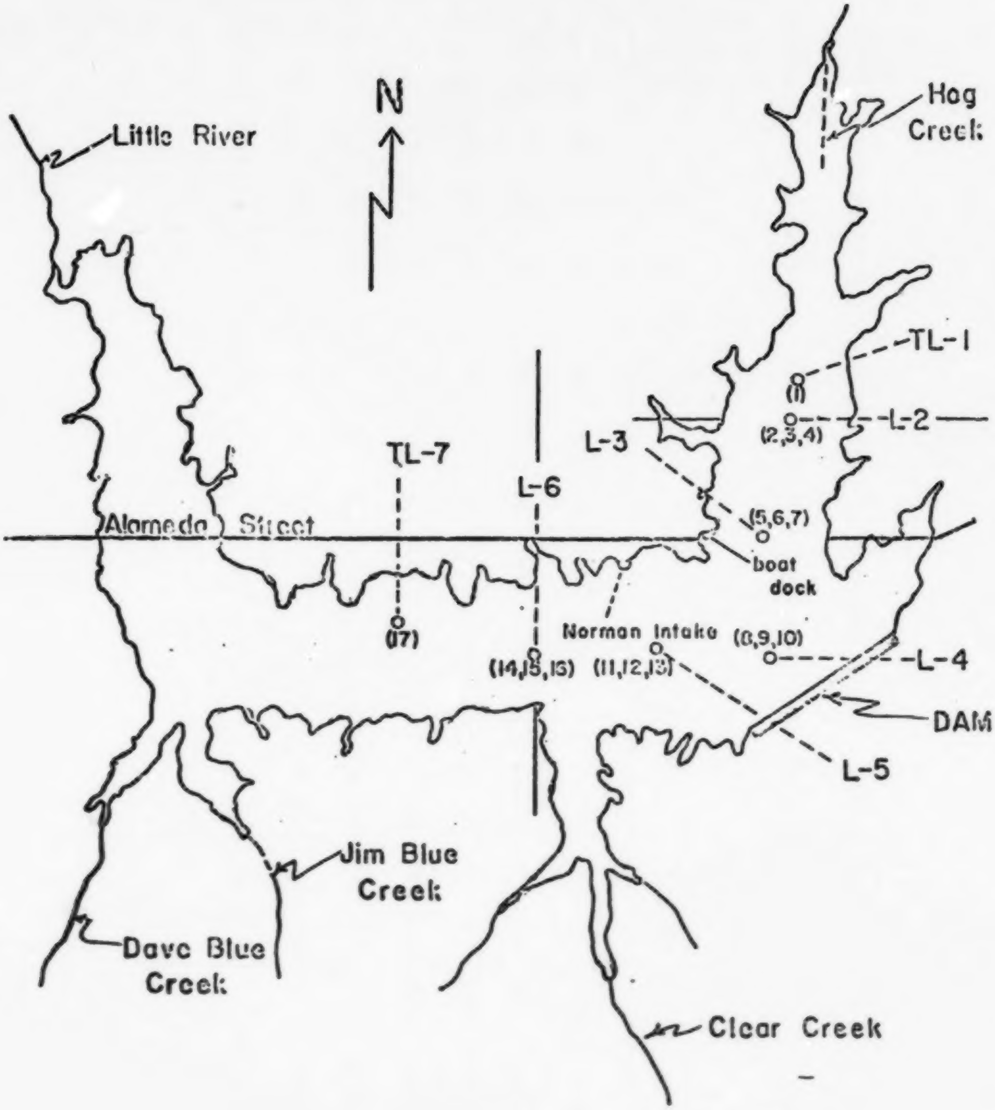
Little River
N
Hog Creek
TL-1
(1)
L-2
(2,3,4)
L-3
(5,6,7)
boat dock
TL-7
L-6
Alameda Street
Norman Intake
(8,9,10)
L-4
(17)
(14,15,16)
(11,12,13)
DAM
L-5
Jim Blue Creek
Dave Blue Creek
Clear Creek

Exhibit 140. Location of Monitoring Station (A-31)

Exhibit 141. SUMMARY OF CHEMICAL ANALYSIS - LAKE THUNDERBIRD(A-31)

Period	pH	Turbidity	TDS	SO_4	Fe	Mn	NH_3	NO_3	NO_2	$O-PO_4$	Tot - PO_4	Cl	Alk.	Tot. Hard.	Ca-Hard.	DO	BOD	COD	Na	H_2O Temp.	
Fall, 1967	8.6	25	277	16	<.1	.43	.61	.32	.01	.02	.26	26	$\frac{0}{180}$	193	100	11	-	-	-	12	
Winter, 1967	8.2	18	305	15	.06	.17	.54	.31	.01	.10	.15	25	$\frac{0}{185}$	197	102	13	-	-	-	4	32
Spring, 1968	7.8	200	267	--	---	---	1.0	.44	---	.01	---	--	$\frac{0}{174}$	214	---	8	-	-	-	17	
Summer, 1968	8.6	29	242	--	---	---	.9	.50	---	.12	---	--	$\frac{0}{215}$	183	---	8	2	13	17	28	82
Fall, 1968	7.6	65	231	17	.3	.41	---	.14	---	.17	---	--	$\frac{0}{173}$	176	---	7	1	13	--	23	
Summer, 1969	7.8	24	270	15	.06	---	.01	.18	---	---	---	--	$\frac{0}{204}$	194	---	7	3	44	16	26	79
Fall, 1969	8.0	26	272	--	---	---	---	.37	---	.25	---	--	$\frac{0}{202}$	198	---	11	2	37	--	13	
Winter, 1969	8.0	5	282	10	<.1	---	---	0.1	---	.19	---	25	$\frac{0}{182}$	202	103	14	4	--	--	--	

Exhibit 142. CHEMICAL ANALYSIS OF SAMPLES FROM VARIOUS LOCATIONS IN WATERSHED(A-31)

(July 25, 1968)

Station	Time	Air Temperature	H_2O Temperature	pH	Turbidity	TDS	DO	NO_3	$O-PO_4$	Alkalinity	Total Hardness	BOD	COD	Na	NH_3
	A.M.														
2	7:30	24.5	23	8.7	35	370	8.5	0.2	0.06	284	308	2.6	42	10	0.6
4	8:15	26.5	24.5	8.6	35	440	4.6	0.3	0.07	448	358		49	31	1.0
5	8:35	24.5	26	8.7	75	600	4.5	0.4	0.19	412	378		50	70	0.7
6	8:50	24.5	24	8.7	35	350	7.6	0.4	0.11	340	310	2.8	4	14	0.9
7	9:00	24.0	24	8.6	20	380	7.0	0.2	0.14	344	298	4.6	9	23	0.7

2. Clear Creek
4. Dave Blue Creek
5. Little River
6. Elm Creek
7. Little River

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Exhibit 142. (Continued) CHEMICAL ANALYSIS OF SAMPLES FROM VARIOUS LOCATIONS IN WATERSHED (A-31)

(August 7, 1968)

Station	Time	Air Temperature	H_2O Temperature	pH	Turbidity	TDS	DO	NO_3	$O\text{-}PO_4$	Alkalinity	Total Hardness	BOD	COD	Na	NH_3
	A.M.														
2	8:15	25.5	23	8.5	25	330	8.5	0.1	0.11	288	290	1	--	10	---
4	8:45	26	24.5	8.4	20	450	1.5	0.2	0.06	436	356	4	--	42	---
5	9:15	27	26	8.2	30	550	4.5	0.1	0.26	388	376	3	--	42	---
6	9:30	27	24	8.4	8	330	7.4	0.1	0.21	280	278	2	--	14	---
7	10:00	31	25.5	8.4	12	340	7.6	0.2	0.21	304	290	2	--	16	---

2. Clear Creek
4. Dave Blue Creek
5. Little River
6. Elm Creek
7. Little River

Page 2 of 2

Exhibit 143. BACTERIA COUNTS--LAKE THUNDERBIRD$^{(A-31)}$

BACTERIA

Colonies per 100 Milliliters

Diurnal - Sampling Station L-4

Total Bacteria

Depth	Date and Time November 2, 1968 2PM	 November 21, 1968 8PM	 November 22, 1968 8AM
Surface	7,500	6,000	11,500
6 meters	6,000	4,000	9,000
12 meters	5,500	7,500	6,500

Coliform

Surface	0	30	40
6 meters	20	50	20
12 meters	30	20	20

Exhibit 144. SUMMARY OF PARTICLE SIZE DISTRIBUTION OF SEDIMENT--LAKE THUNDERBIRD

	Percent of sediment with diameter less than (millimeters)						
Location	0.001	0.005	0.01	0.05	0.01	0.15	1.0
TL-1	24	35	41	67	90	100	100
L-2	14	21	26	41	62	100	100
L-3	44	61	70	83	90	100	100
L-4	66	85	90	99	100	100	100
L-5	61	82	90	99	100	100	100
L-6	14	16	22	60	90	100	100
TL-7	14	15	18	65	92	100	100

Case 24. Sedimentation of Loch Raven and Prettyboy Reservoirs, Baltimore County, Maryland*

Source -

John N. Holeman, Sedimentation of Loch Raven and Prettyboy Reservoirs, Baltimore County, Maryland, U. S. Department of Agriculture, Soil Conservation Service, SCS-TP-145, February 1965. (A-27)

Purposes-

1. To compare the present rate of sedimentation with that before 1943 to evaluate the effects of land use changes and soil conservation measures implemented since 1943.
2. To determine the present and predict the future capacities of the two reservoirs.
3. To develop a method to estimate the effects of land treatment as a way to extend reservoir life (for the Northern Piedmont Physiographic Province).

Site Location/Description -

Both reservoirs are located on the Gunpowder Falls River in Northeastern Baltimore County. The River empties into the Chesapeake Bay just north of the City of Baltimore. The Loch Raven Dam is 9 miles above the Bay and Prettyboy Dam is 22 miles above the Loch Raven. The stream extends another 18 miles beyond the Prettyboy Dam into York County, Pennsylvania.

Both reservoirs are long and narrow (Loch Raven - 10-1/2 miles; Prettyboy 7-1/4 miles) within irregular shoreline. The Prettyboy drainage basin is 80 sq. mi. and Loch Raven drains 223 sq. mi. (excluding the area draining into the Prettyboy.) The original areas of the reservoirs were 2,391 acres for the Loch Raven and 1,498 acres for Prettyboy. The Loch Raven Dam is 75 feet above the streambed and 246 feet above sea level. The Loch Raven was built in 1881 and the Prettyboy added in 1933. They are used as a water supply for Baltimore.

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*This study pertains to the operational aspects of impoundments and the effects of siltation, rather than the pollution effects of reservoir construction.

Topography -

The elevation of the drainage basins extends to 920 feet for a vertical rise of 749 feet from the base of the Loch Raven Dam. There are three main types of topography: summit uplands, narrow valleys and wide meadows. The most important are the steep narrow valleys which control the shape of the Prettyboy reservoir, and to a lesser extent the Loch Raven causing an irregular shoreline with many narrow coves. There is a little residual soil on the valley walls and much of the lake bottom is exposed bedrock. This topography also limits development. The lower reaches of the Loch Raven are underlain by a less resistant marble allowing broader bays and therefore greater sediment accumulation. The streams draining the basin tend to be steep and have formed deep valleys through the crystaline rocks. The meadows occupy a small part of the lower watershed.

Soil Types -

The authors have defined 6 soil associations. The extent and estimated erosion losses are given in Exhibits 145 through 147. The most important are numbers 1, 2, and 3. Association 1 is the Conestoga-Hagerstown group, occupying the lowlands of the south-central part of the Loch Raven watershed. It is based on the weathered calcareous bed rock and is the most productive in the watershed. Hence they are intensively cultivated. Because of their gentle slopes and their moderate erodibility, they have not been a major sediment source.

Association 2 is the Chester-Glenergy-Elioak Association occupying the plateaus of the uplands. This soil type is moderately erodible and quite productive, being the most intensly culitvated soil of the Prettyboy

Exhibit 145. AREA AND PROPORTIONAL EXTENT OF SOIL ASSOCIATIONS(A-27)

Soil association	Loch Raven Watershed		Prettyboy Watershed		Two watersheds	
	Acres	Percent	Acres	Percent	Acres	Percent
1. Conestoga-Hagerstown	20,490	14.4	0	0	20,490	10.5
2. Chester-Glenelg-Elioak..............	49,960	35.0	32,900	64.3	82,860	42.7
3. Manor-Glenelg........	56,410	39.5	6,910	13.5	63,320	32.7
4. Manor channery loam.	0	0	2,730	5.3	2,730	1.4
5. Sassafras............	1,120	.8	0	0	1,120	.6
6. Stony steep land....	12,350	8.6	7,160	14.0	19,510	10.1
Reservoir surface......	2,390	1.7	1,500	2.9	3,890	2.0
Total area...........	142,720	100.0	51,200	100.0	193,920	100.0

Exhibit 146. DISTRIBUTION OF SLOPE(A-27)

Loch Raven Watershed (excluding Prettyboy)

Slope	Soil association						Total land area
	1	2	3	4	5	6	
	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
Nearly level (0-3 percent)...	13	5	5	0	0	37	9
Gentle (3-8 percent)..........	72	61.5	22	0	37	11	42
Moderate (8-15 percent).......	15	30	35	0	61	2	27
Strong (15-25 percent)........	0	3	27	0	2	7	13
Steep (25-45 percent).........	0	0.5	11	0	0	35	8
Very steep (>45 percent)......	0	0	0	0	0	8	1
Total land area.............	14.6	35.6	40.2	0	0.8	8.8	100

Prettyboy Watershed

Slope	1	2	3	4	5	6	Total land area
Nearly level (0-3 percent)...	0	11	10	0	0	3	9
Gentle (3-8 percent)..........	0	48	12	15	0	2	35
Moderate (8-15 percent).......	0	32	28	33	0	0	27
Strong (15-25 percent)........	0	8	36	30	0	9	13
Steep (25-45 percent).........	0	1	14	22	0	73	14
Very steep (>45 percent)......	0	0	0	0	0	13	2
Total land area.............	0	66.2	13.9	5.5	0	14.4	100

Exhibit 147. ESTIMATED SHEET EROSION IN 1940 AND 1960(A-27)

Loch Raven Watershed

Soil association	Soil loss in 1940			Soil loss in 1960		
	Amount	Proportion of total loss	Annual rate	Amount	Proportion of total loss	Annual rate
	Tons	Percent	Tons per acre	Tons	Percent	Tons per acre
1.......	124,480	7.1	6.08	45,900	6.6	2.24
2.......	479,620	27.2	9.60	191,840	27.5	3.84
3.......	1,119,270	63.5	19.84	433,230	62.3	7.68
5.......	3,410	.2	3.04	1,790	.2	1.60
6.......	35,570	2.0	2.88	23,710	3.4	1.92
Total	1,762,350	100.0	12.56	696,470	100.0	4.96

Prettyboy Watershed

Soil association	Amount	Proportion of total loss	Annual rate	Amount	Proportion of total loss	Annual rate
2.......	263,200	52.0	8.00	126,340	47.2	3.84
3.......	140,420	27.7	20.32	74,080	27.6	10.72
4.......	66,640	12.8	23.68	29,700	11.1	10.88
6.......	37,810	7.5	5.28	37,810	14.1	5.28
Total	508,070	100.0	9.98	267,930	100.0	5.28

watershed (the Conestoga-Hagerstown is absent). Because of the scarcity of well defined channels, little of this soil reaches the Loch Raven, while in contrast, due to its extensiveness and proximity to the reservoir, it accounts for nearly half the sediment of the Prettyboy.

Association 3 is the most prevalent of the Loch Raven watershed and is also common above the Prettyboy, although not as extensive. This soil occurs on the moderate slopes between sloping uplands (2) and steep valley walls (6). These soils are highly erodible, especially when the subsoil has been exposed. Due to the steep slope, intensive cultivation and its high degree of erodibility, this soil is the major sediment source to Loch Raven and an important source to Prettyboy.

Land Use -

According to the records of the Division of Agriculture, U. S. Bureau of Census, the area of farm land greatly decreased during the period between the two studies. In addition, 47 percent of the remaining farm land was being operated under a basic conservation program (see Exhibits 148, 149, 150, and 151.

Method of Survey -

Water depths and sediment cores were taken along 43 ranges across the lakes at various places (Exhibits 152 and 153. The cores were then examined to determine the depth of recent deposits. The data were then used to compute the original capacity, sediment volume and the accumulation rates. These were compared with the results of a 1943 survey by L. C. Gottschalk of the Soil Conservation Service. In addition, some interesting observations were made on sediment distribution in the reservoirs (see Exhibits 154 and 155.)

Time Frame -

The original Loch Raven Dam was built in 1881. A new dam was built in 1912 just upstream from the first, and was heightened by 50 feet in 1922.

Exhibit 148. LAND USE CHANGES IN LOCH RAVEN AND PRETTYBOY WATERSHEDS(A-27)

Land use	Loch Raven		Prettyboy	
	1939	1959	1939	1959
	Percent	Percent	Percent	Percent
Cropland................	41.5	18.4	58.1	15.3
Plowable pasture........	8.5	6.0	4.0	5.8
Woodland................	15.8	6.6	16.2	2.1
Other land in farms.....	9.3	2.4	12.1	1.0
Land not in farms.......	24.9	66.6	9.6	75.8

Exhibit 149. LAND USE IN BALTIMORE COUNTY, MD.(A-27)

Land use	1940	1945	1950	1955	1960
	Percent	Percent	Percent	Percent	Percent
Cropland................	32.0	36.3	32.1	25.5	18.1
Pasture.................	8.2	10.7	8.0	8.2	6.2
Woodland................	14.2	16.1	12.7	10.3	7.2
Other...................	45.6	36.9	47.2	56.0	68.5
Total...................	100.0	100.0	100.0	100.0	100.0

Exhibit 150. PERCENT OF AGRICULTURAL LANDS IN VARIOUS CONSERVATION USES(A-27)

	Percent of agricultural land
On cropland:	
Conservation crop rotations........	22
Contour farming........................	22
Cover cropping........................	2
Strip cropping..........................	17
On grassland:	
Hayland planting.......................	7
Pasture improvement................	7
Pasture planting.......................	7
Rotation grazing.......................	20
On farm woodland:	
Tree planting...........................	2
Woodland improvement..............	4
Woodland protection................	5

Exhibit 151. AREA AND PROPORTIONATE EXTENT OF LAND-CAPABILITY CLASSES (A-27)

Land-capability class	Loch Raven Watershed		Prettyboy Watershed	
	Acres	Per-cent	Acres	Per-cent
Land suitable for cultivation and other uses:				
Class I--These soils have few or no conditions that limit their use. They can be safely cultivated without special conservation treatment.	420	0.3	15	0.1
Class II--These soils have some natural condition that limits the kinds of plants they can produce or that calls for some easily applied conservation practice when they are cultivated.	52,480	37.4	16,350	32.9
Class III--These soils have more serious or more numerous limitations than those in Class II. The limitations may be natural ones--such as steep slope, sandy or shallow soil, or too little or too much water. Or the limitations may be erosion brought on by the way the land has been used. Thus they are more restricted in the crops they can produce or, when cultivated, call for conservation practices more difficult to install or keep working efficiently.	37,330	26.6	13,760	27.7
Land suitable for occasional cultivation and other uses:				
Class IV--These soils have very severe limitations that restrict the kind of plants they can grow. If cultivated, they require very careful management. In humid areas, they are suitable for occasional but not regular cultivation; in subhumid and semi-arid areas, crops fail in years of low rainfall.	11,230	8.0	6,410	12.9
Land generally not suitable for cultivation but suitable for other uses:				
Class V--These soils have little or no erosion hazard but have some condition impractical to remove that limits their use largely to pasture, range, woodland, recreation, or wildlife food and cover.	0	0	0	0
Class VI--These soils have very severe limitations that make them generally unsuited to cultivation and restrict their use largely to pasture, range, woodland, recreation, or wildlife food and cover.	27,790	19.8	8,000	16.1
Class VII--These soils have very severe limitations that make them unsuited to cultivation and that restrict their use to pasture, range, woodland, recreation, or wildlife food and cover with careful management.	9,960	7.1	4,720	9.5
Class VIII--These soils and landforms have limitations that prevent their use for commercial plant production and that restrict their use to recreation, water supply, or wildlife food and cover with careful protection.	1,120	.8	445	.9
Total..	140,330	100.0	49,700	100.0

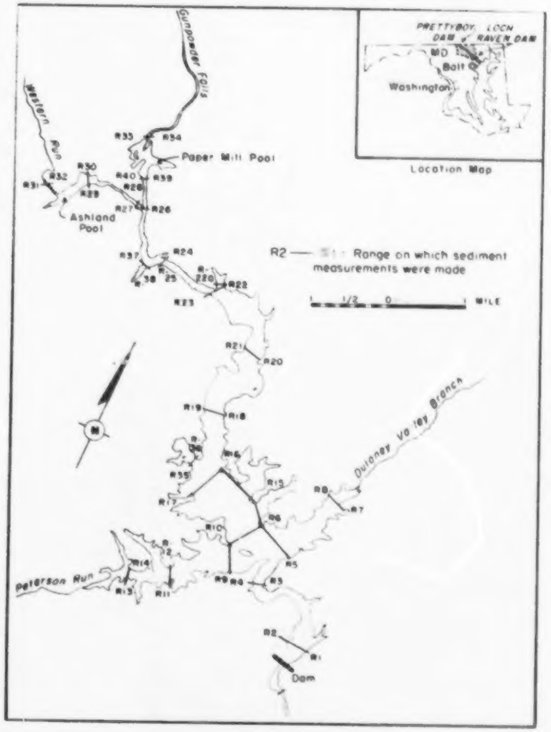

PRETTYBOY LOCH DAM RAVEN DAM
MD
Balt
Washington
Location Map
R2 —— R1 : Range on which sediment measurements were made
1/2 0 1 MILE
Gunpowder Falls
Western Run
Paper Mill Pool
Ashland Pool
Gunpowder Valley Branch
Peterson Run
Dam
N

Exhibit 152. Loch Raven Reservoir$^{(A-27)}$

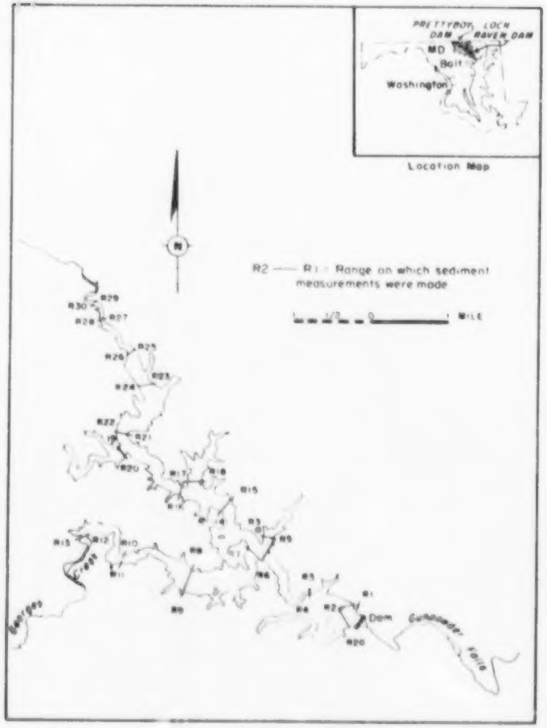
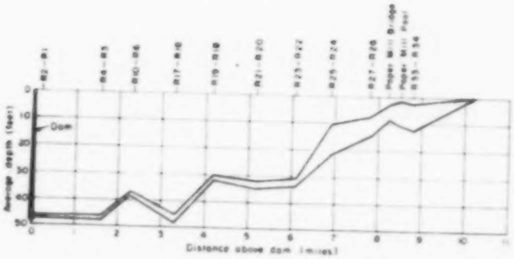
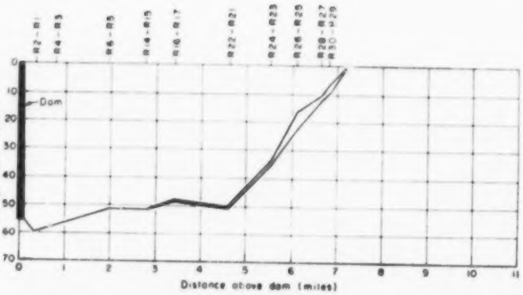

PRETTYBOY LOCH DAM RAVEN DAM
MD
Balt
Washington
Location Map
R2 —— R1 : Range on which sediment measurements were made
1/2 0 1 MILE
Georges Creek
Gunpowder Falls
Dam
N

Exhibit 153. Prettyboy Reservoir$^{(A-27)}$



*See Exhibit 152 for
location of ranges (R's)

Exhibit 154. Distribution of Sediment
in Loch Raven Reservoir (A-27)



See Exhibit 153 for
location of R's

Exhibit 155. Distribution of Sediment
in Prettyboy Reservoir (A-27)

The Prettyboy Dam was built in 1933, removing 80 square miles of the Loch Raven watershed. Gottschalk's study was performed in October, 1943 and the present study in 1961.

The average annual precipitation increased from 41.83 inches between 1914 and 1943 to 44.4 inches between 1944 and 1960, an increase of 6 percent. The average annual rainfall from large storms (exceeding 2, 3 and 4 inches/24 hours) also increased during this period. The computed average annual surface runoff increased from 3.07 to 3.53 inches.

The data summary sheets are presented as Exhibits 156 and 157. In contrast to the runoff figures, the sediment accumulation rates determined in the 1961 study were less than a third of the 1943 rate for the Loch Raven and just over half the 1943 rate in the Prettyboy. The data is given in Exhibit 158. According to the sediment distribution charts and the clarity of the discharge at the dams, it is apparent that both reservoirs trap essentially all the influent sediment so that the measured accumulation rates are valid.

Conclusions -

Gottschalk's 1943 report concluded that the primary sediment source was sheet erosion of cultivated land. He suggested improved soil conservation measures. Since then, there has been a large reduction of agricultural land and the remaining land has been subject to soil management programs (see Exhibit 150). In addition the change from agricultural to nonfarm (mostly residential) uses has been scattered and did not include extensive deundation, as might have occurred for shopping centers or other large urban developments. The third major factor helping to reduce the sediment load is the forested land owned by the city of Baltimore which borders the reservoirs. This land comprises about 6 percent of the watershed and is being maintained for recreation and timber development.

Exhibit 156. SUMMARY OF SEDIMENTATION DATA FOR LOCH RAVEN RESERVOIR(A-27)

RESERVOIR SEDIMENT DATA SUMMARY
SCS-34 Rev. 6-62

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

NAME OF RESERVOIR: Loch Raven Reservoir

DATA SHEET NO.: 4 - 1

DAM	1. OWNER Dept. Public Works, Baltimore	2. STREAM Gunpowder Falls	3. STATE Maryland
	4. SEC. TWP RANGE	5. NEAREST TOWN Towson	6. COUNTY Baltimore
	7. STREAM BED ELEVATION 171	8. TOP OF DAM ELEVATION 246	9. SPILLWAY CREST ELEV. 240

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA ACRES	13. ORIGINAL CAPACITY ACRE-FEET	14. GROSS STORAGE ACRE-FEET	15. DATE STORAGE BEGAN
	a. MULTIPLE USE					1914
	b. FLOOD CONTROL					
	c. POWER					
	d. WATER SUPPLY	240	2,391	70,169 1/ 2/	70,169 1/ 2/	16. DATE NORMAL OPER. BEGAN
	e. IRRIGATION					1914
	f. CONSERVATION					
	g. SEDIMENT					
	h. INACTIVE					

17. LENGTH OF RESERVOIR 10.5 MILES | AV. WIDTH OF RESERVOIR .3 MILES

WATERSHED	18. TOTAL DRAINAGE AREA 303 SQ. MI.		22. MEAN ANNUAL PRECIPITATION 42.53 INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 219.4 3/ SQ. MI.		23. MEAN ANNUAL RUNOFF INCHES
	20. LENGTH 50 MILES	AV. WIDTH 6 MILES	24. MEAN ANNUAL RUNOFF AC.-FT.
	21. MAX. ELEV. 920	MIN. ELEV. 171	25. CLIMATIC CLASSIFICATION Humid

SURVEY DATA

26. DATE OF SURVEY	27. PERIOD YEARS	28. ACCL. YEARS	29. TYPE OF SURVEY	30. NO. OF RANGES OR CONTOUR INT.	31. SURFACE AREA ACRES	32. CAPACITY ACRE-FEET	33. C/W RATIO AC.-FT. PER SQ. MI.
1914	-	-	-	-	2,391	70,169 1/ 2/	231 1/ 2/
Oct. 1943	29	29	Range Recon.	18	2,337	64,813 2/	214 2/
June 1961	18	47	Range Detail	24	2,332	64,072	211

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW ACRE-FEET			36. WATER INFL. TO DATE AC.-FT.	
		a. MEAN ANNUAL	b. MAX. ANNUAL	c. PERIOD TOTAL	a. MEAN ANNUAL	b. TOTAL TO DATE

26. DATE OF SURVEY	37. PERIOD SEDIMENT DEPOSITS ACRE-FEET			38. TOTAL SED. DEPOSITS TO DATE ACRE-FEET		
	a. PERIOD TOTAL	b. AV. ANNUAL	c. PER SQ. MI.-YEAR	a. TOTAL TO DATE	b. AV. ANNUAL	c. PER SQ. MI.-YEAR
Oct. 1943	5,356	185	.618 3/	5,356	185	.618 3/
June 1961	741	41	.187	6,097	130	.593

26. DATE OF SURVEY	39. AV. DRY WGT. LBS. PER CU. FT.	40. SED. DEP. TONS PER SQ. MI.-YR.		41. STORAGE LOSS PCT.		42. SED. INFLOW PPM	
		a. PERIOD	b. TOTAL TO DATE	a. AV. AN.	b. TOT. TO DATE	a. PERIOD	b. TOT. TO DATE
Oct. 1943	60 4/	808 2/	808 2/	.26 2/	7.63 2/		
June 1961	55.0 (11)	233	740	.18	8.69		

1/ Based on original potential capacity to 240' elevation

2/ Revised after 1961 survey

3/ Net sediment contributing area was 299.4 sq.mi. until 1933 when Prettyboy dam was completed. This area was used in 1943 calculations.

4/ Assumed

Exhibit 157. SUMMARY OF SEDIMENTATION DATA FOR PRETTYBOY RESERVOIR

RESERVOIR SEDIMENT DATA SUMMARY
SCS-34 Rev. 6-62

Prettyboy Reservoir
NAME OF RESERVOIR

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

4 - 2
DATA SHEET NO.

DAM	1. OWNER Dept. Public Works Baltimore	2. STREAM Gunpowder Falls	3. STATE Maryland
	4. SEC. TWP. RANGE	5. NEAREST TOWN Hereford	6. COUNTY Baltimore
	7. STREAM BED ELEVATION 387	8. TOP OF DAM ELEVATION 540	9. SPILLWAY CREST ELEV. 520

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA ACRES	13. ORIGINAL CAPACITY ACRE-FEET	14. GROSS STORAGE ACRE-FEET	15. DATE STORAGE BEGAN
	a. MULTIPLE USE					April 10 1933
	b. FLOOD CONTROL					
	c. POWER					
	d. WATER SUPPLY	520	1,498	60,979 1/	60,979 1/	16. DATE NORMAL OPER. BEGAN
	e. IRRIGATION					
	f. CONSERVATION					October 1933
	g. SEDIMENT					
	h. INACTIVE					

	17. LENGTH OF RESERVOIR 7.25 MILES	AV. WIDTH OF RESERVOIR .32 MILES
WATERSHED	18. TOTAL DRAINAGE AREA 80 SQ. MI.	22. MEAN ANNUAL PRECIPITATION 42.53 INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 77.5 SQ. MI.	23. MEAN ANNUAL RUNOFF INCHES
	20. LENGTH 12 MILES AV. WIDTH 6.67 MILES	24. MEAN ANNUAL RUNOFF AC.-FT.
	21. MAX. ELEV. 920 MIN. ELEV. 387	25. CLIMATIC CLASSIFICATION Humid

SURVEY DATA

26. DATE OF SURVEY	27. PERIOD YEARS	28. ACCL. YEARS	29. TYPE OF SURVEY	30. NO. OF RANGES OR CONTOUR INT.	31. SURFACE AREA ACRES	32. CAPACITY ACRE-FEET	33. C/W RATIO AC.-FT. PER SQ. MI.
April 1933	-	-	-	-	1498	60,979 1/	762 1/
Oct. 1943	10.5	10.5	Range Recon.	14	1498	60,410 1/	755 1/
Sept. 1961	18	28.5	Range Detail	23	1467	59,864	748

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW ACRE-FEET			36. WATER INFL. TO DATE AC.-FT.	
		a. MEAN ANNUAL	b. MAX. ANNUAL	c. PERIOD TOTAL	a. MEAN ANNUAL	b. TOTAL TO DATE

26. DATE OF SURVEY	37. PERIOD SEDIMENT DEPOSITS ACRE-FEET			38. TOTAL SED. DEPOSITS TO DATE ACRE-FEET		
	a. PERIOD TOTAL	b. AV. ANNUAL	c. PER SQ. MI.-YEAR	a. TOTAL TO DATE	b. AV. ANNUAL	c. PER SQ. MI.-YEAR
Oct. 1943	569	54.2	.699	569	54.2	.699
Sept. 1961	546	30.3	.391	1115	39.1	.504

26. DATE OF SURVEY	39. AV. DRY WGT. LBS. PER CU. FT.	40. SED. DEP. TONS PER SQ. MI.-YR.		41. STORAGE LOSS PCT.		42. SED. INFLOW PPM	
		a. PERIOD	b. TOTAL TO DATE	a. AV. AN.	b. TOT. TO DATE	a. PERIOD	b. TOT. TO DATE
Oct. 1943	60 2/	913	913	0.09	0.93		
Sept. 1961	62.8(14)	547	705	0.06	1.83		

1/ Revised after 1961 survey
2/ Assumed

Exhibit 158. RATE OF SEDIMENT ACCUMULATION IN 16 RESERVOIRS IN NORTHERN PART OF PIEDMONT PROVINCE (A-27)

Reservoir	Location	Age at date of survey	Original capacity	Total drainage area	Latest capacity-watershed ratio	Annual storage loss	Annual sediment-accumulation rat
		Years	Acre-feet	Square miles	Acre-feet per square mile	Percent	Acre-feet per square mile
Greenbelt.......	Greenbelt, Md.	21.1	196	0.83	182	1.09	2.57
Palington.......	Spring Grove, Pa.	1.6	63	2.91	21	3.09	.669
Loch Raven......	Towson, Md.	47	70,169	303	211	.18	.593
New Glatfelter..	York, Pa.	2	62	3.0	21	2.85	.592
Prettyboy.......	Hereford, Md.	28.5	60,979	80	748	.06	.504
Barecroft.......	Alexandria, Va.	42.6	1,847	14.5	144	.38	.473
Burnt Mills.....	Silver Spring, Md.	7.8	181	27.0	3.5	6.08	.408
Williams........	York, Pa.	27	2,686	42.9	52	.63	.394
Atkisson........	Bel Air, Md.	12	896	45.46	16	1.78	.351
Coatesville.....	Coatesville, Pa.	35	1,019	5.0	194	.14	.28
Triadelphia.....	Ashton, Md.	16.2	20,222	81.4	241	.08	.20
Jackson.........	Manassas, Va.	7.2	4,500	337.0	12.3	1.06	.141
Pedlar..........	Oronoco, Va.	31	1,860	33.21	52	.24	.134
Old Glatfelter..	York, Pa.	55	147	74.3	0.1	1.69	.033
Icedale.........	Chester Co., Pa.	51	137	20.0	5.3	.04	.03
Fishing Creek...	Frederick, Md.	12	236	8.5	28	.03	.007

This study demonstrates the benefits of sensible conservation measures, both in improved agricultural practices and in reforestation of the land adjacent to the reservoirs. These techniques have effectively decreased the sediment loading and considerably extended the life of the lakes.

APPENDIX D: EFFECTS OF CHANNELIZATION ON WATER QUALITY

General

This appendix contains summaries of three case studies on channelization. One of these contains limited information about water quality effects based on fish concentration; the others pertain largely to channel characteristics and hydrologic effects.

Case 25. Channelization of Blackwater Creek in Missouri

Source -

John W. Emerson, "Channelization - A Case Study," Science, Vol. 173, July 1971, pp 325-326.(A-17)

Purpose -

This study was conducted to determine the effects of channelization in the Blackwater River, 60 years after the original channel was dredged.

Site Location/Description -

The Blackwater River originates in northwest Jackson County, Missouri, approximately 65 km east of Kansas City. The river flows east, joining the Missouri River west of Boonville, Missouri. In 1910 a new channel was dredged for a 53.6 km section of the river in the eastern part of the county.

Topography -

The original channel had an average of 1.8 meanders per kilometer with a meander radius between 60 and 140 km. The replacement channel was 9 m wide at the top, 1 m at the bottom and 3.8 m deep. The cross-sectional area was 19 m^2. The new channel length is 29 km for a gradient of 3.1 m/km.

Geology -

The lithology of the channelized area consists of thin-beeded Pennsylvanian shale, coal, sandstone and limestone. This composition changes near the Saline County line to the harder Mississippian limestone. The softer rock in Jackson County permitted easy dredging up to the harder limestone at the county line.

Study Method -

Present channel dimensions and bridge lengths were compared to the original ditch size and both the old channel and original new channel bridge lengths. The amount of fish expressed as Kg per acre was compared for the present channelized and unchannelized reaches. The frequency of flooding before and after channelization is also noted.

Results -

The original dredged channel increased in size from 19 m^2 area and 9 m width at the top to sizes ranging from 130 m^2 and 29 m wide to 484 m^2 and 71 m wide during the 60 years since its modification. (See Exhibit 159.) This increase in width has caused the destruction by erosion of almost all the bridges over the new channel. One bridge has been replaced five times.

The river has not begun to meander and flows in essentially the same channel. The rate of erosion for the central section has been determined to cause an increase of 1 meter in width and 0.16 m in depth each year. Erosion of the soft bedrock has produced a smooth chutelike channel bottom that does not support bottom fauna. This has resulted in a concentration of only 51 kg of fish per acre compared to 256 kg per acre in the unchannelized portions.

A further problem is caused by the transition from the soft rock underlying the new channel to the harder, less erodible rock downstream. Erosion of the unchannelized downstream reach hasn't kept pace with the erosion of the channelized reach. Therefore, where the channelized reach has a capacity of 280 to 850 m^3 per second, the downstream reach has a capacity of only 170 to 255 m^3 per second. This results in frequent flooding and consequent silt and debris deposition in the area around the end of the channelized stream, whereas extensive flooding

Exhibit 159. DIMENSIONS OF THE PRESENT BLACKWATER RIVER IN JOHNSON AND SALINE COUNTIES, MISSOURI. SIZE OF THE ORIGINAL CHANNEL: WIDTH AT TOP, 9m; WIDTH AT BOTTOM, 1m; AND DEPTH, 3.8m (A-17)

Bridge Location	Present Channel Dimensions			
	Top Width (m)	Bottom Width (m)	Depth (m)	Cross-Sectional Area (m)
a. North Fork, Route 131	21.9	7.0	4.7	67.9
b. South Fork, Route 131	20.1	5.0	4.1	51.2
c. North Fork	67.6	9.2	9.2	353.2
d. South Fork Route 50	45.7	12.2	9.4	280.1
e. Elevation, 729 feet (222 m)	53.3	12.8	10.9	360.2
f. Elevation, 711 feet (217 m)	60.9	11.6	10.0	362.5
g. Elevation, 696 feet (212 m)	64.0	22.8	10.0	434.0
h. Bear Creek	71.0	12.5	11.6	484.3
i. Valley City	51.8	15.8	8.2	277.1
j. Route J	35.0	15.2	6.4	160.6
k. Dunksburg	29.8	15.2	5.8	130.5
l. Sweet Springs	42.7	15.3	5.8	168.2

of this area was uncommon before 1910. Overbank deposits 2 meters deep have buried two generations of fence posts on the flood plain at the county line.

The referenced study points out the true cost elements of arbitrary channelization in terms of bridge repair, erosion loss, and flood damage.

Case 26. Effects of Man's Manipulation of the Willow River Channel, Iowa

Source -

Ruhe, R. V., "Stream Regimen and Man's Manipulation," in *Environmental Geomorphology*, Coates Publishing Co., 1970.(A-44)

Purpose -

This study was performed to analyze the effects of the straightening of the channel of the Willow River in Southwestern Iowa in order to design conservation programs which will aid in alleviating the problems that have resulted.

Site Location/Description -

Willow River heads in Crawford County Iowa, approximately 50 miles northeast of the Missouri River and flows southwest through Monona and Harrison Counties where it joins the Boyer River which eventually drains into the Missouri River.

Soil Type -

The stream and drainage ditch cut into compact silts which were generated by the upland loess. Sands and gravel which came from glacial till appear only in certain areas of the valley.

Stream Topography -

Prior to engineering improvements, stream length in Harrison County was 23.6 miles for a valley length of 20.2 miles. Bank width ranged from 60 to 100 feet with a channel depth of 10 to 12 feet. Lower reach gradient ranged from 1.7 to 7.9 ft/mi with an average of 5.2 ft/mi. Upper reach gradient averaged 7.5 ft/mi within a range of 4.6 to 12.2 ft/mi. Engineering modifications to the channel are summarized in Exhibit 160.

Exhibit 160. SUMMARY OF CHANNEL MODIFICATIONS OF WILLOW RIVER(A-44)

Improvement #	Date of Construction	Length	Channel Bottom Width	Side Slope	Depth	Gradient
1 (lower reach)	1906-1908	6.6 mi.	18 ft.	1:1	15	2 ft/mi
2 (middle reach)	1916-1919	10.2 mi.	12 ft.	1:1	15	7.5 ft/mi
3 (upper reach)	1919-1920	11.5 mi.	12 to 8 ft.	1:1	11	8.5 to 12 ft/mi

Study Method -

Longitudinal profiles of the channel bottom and transverse profiles of the ditch were made at various times by R. B. Daniels using bridge records from official state and county highway files ("Entrenchment of the Willow Drainage Ditch, Harrison, Co., Iowa, "Am. Journal of Science, Vol. 258, pp. 161-176). Daniels also measured nickpoints which were reported by residents.

Results -

Willow Creek drainage ditch has deepened its channel over the years. This deepening is seen in Exhibit 161. At the mouth of Thompson Creek, the ditch has deepened about 9 feet between 1919 and 1936, about 4 feet between 1936 and 1942, and about 5 feet between 1942 and 1957. The effects of this deepening on stream profiles in the Thompson Creek Watershed are shown in Exhibits 162 and 163.

Generally, the effect has been to cause entrenchment of Thompson Creek and its major branches (See Exhibit 162). In 1916, the Thompson Creek channel was only 14 feet deep and in 1908, near the junction of Turton Branch and Thompson Creek, the channel was 10 to 15 feet deep. Now the depth of the channel approaches 40 feet at the confluence of Thompson Creek and Willow River.

Effects have been felt in the transportation network of the area. Roads and bridges pose a major maintenance problem while agricultural vehicles have to go around or over stream tributaries rather than through them. The water table has also been lowered from the 1918 level of 20-25 feet to a present depth of 35 feet or more. The flood control aspects of the project have been successful, however.

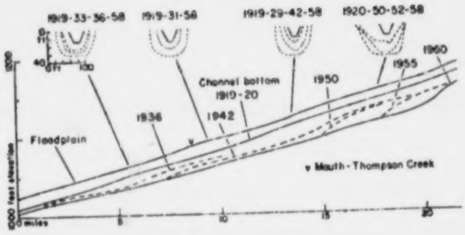


Exhibit 161. Longitudinal and Transverse Profiles of Willow Drainage Ditch During Specific Years

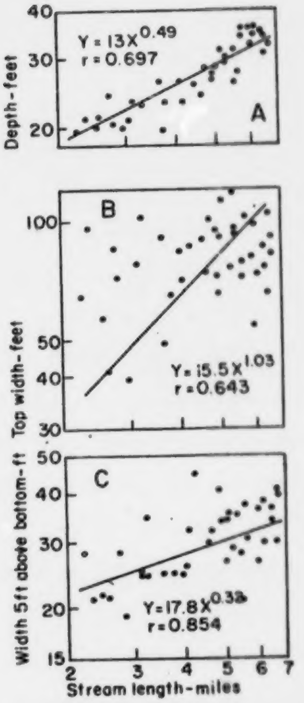


Exhibit 163. Deepening and Widening of Thompson Creek

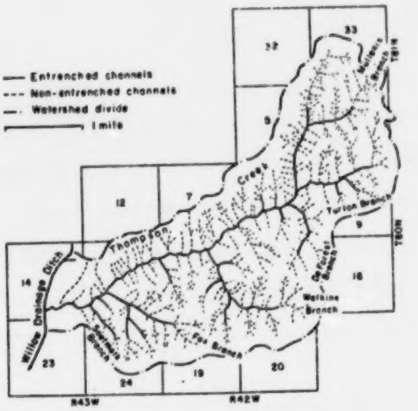

Entrenched channels
Non-entrenched channels
Watershed divide
1 mile
32
33
5
12
7
14
23
24
19
20
9
16
Thompson
Creek
Willow Drainage Ditch
Turlon Branch
Watkins Branch
Fox Branch
Branch
T81N
T80N
R43W
R42W

Exhibit 162. Drainage Net of Thompson Creek Watershed Showing Extent of Major Entrenchment

Case 27. Evaluation of Forty-two Channel Modification Projects

Source -

Arthur D. Little Inc., Report on Channel Modifications, The President's Council on Environmental Quality, Washington, D.C., 1973.(A-2)

Purpose -

This report was compiled to provide a factual assessment of selected channelization projects in the United States; it assesses environmental, economic, financial, and engineering aspects of channel modifications as well as the various alternatives which are considered by the Corps of Engineers, Soil Conservation Service, Tennessee Valley Authority, and the Bureau of Reclamation.

Site Locations and Descriptions -

Forty-two different sites were chosen for study in this report using the following criteria: geographic dispersion; climate, soil, and water variations; habitat variations; terrain variations; differences in purpose; whether or not water impoundments are involved, in conjunction with water conveyance capacities; rural or urban locale, or both; whether "in tandem," upstream or downstream of another agency project; time of installation; availability of pre-project data; and magnitude of channel works. By definition of these criteria alone, it is apparent that all sites differed greatly in terms of topography, soil type, ground cover and land use, climate and rainfall. An adequate range of conditions existed in each of these categories. Exhibit 164 shows the location of the sites listed in Exhibit 165. The latter exhibit gives a gross indication of the magnitude of each project.

Study Method -

Forty-two channelization projects were chosen as study sites through the criteria outlined above. Each site evaluation was overseen by

Reproduced from best available copy.

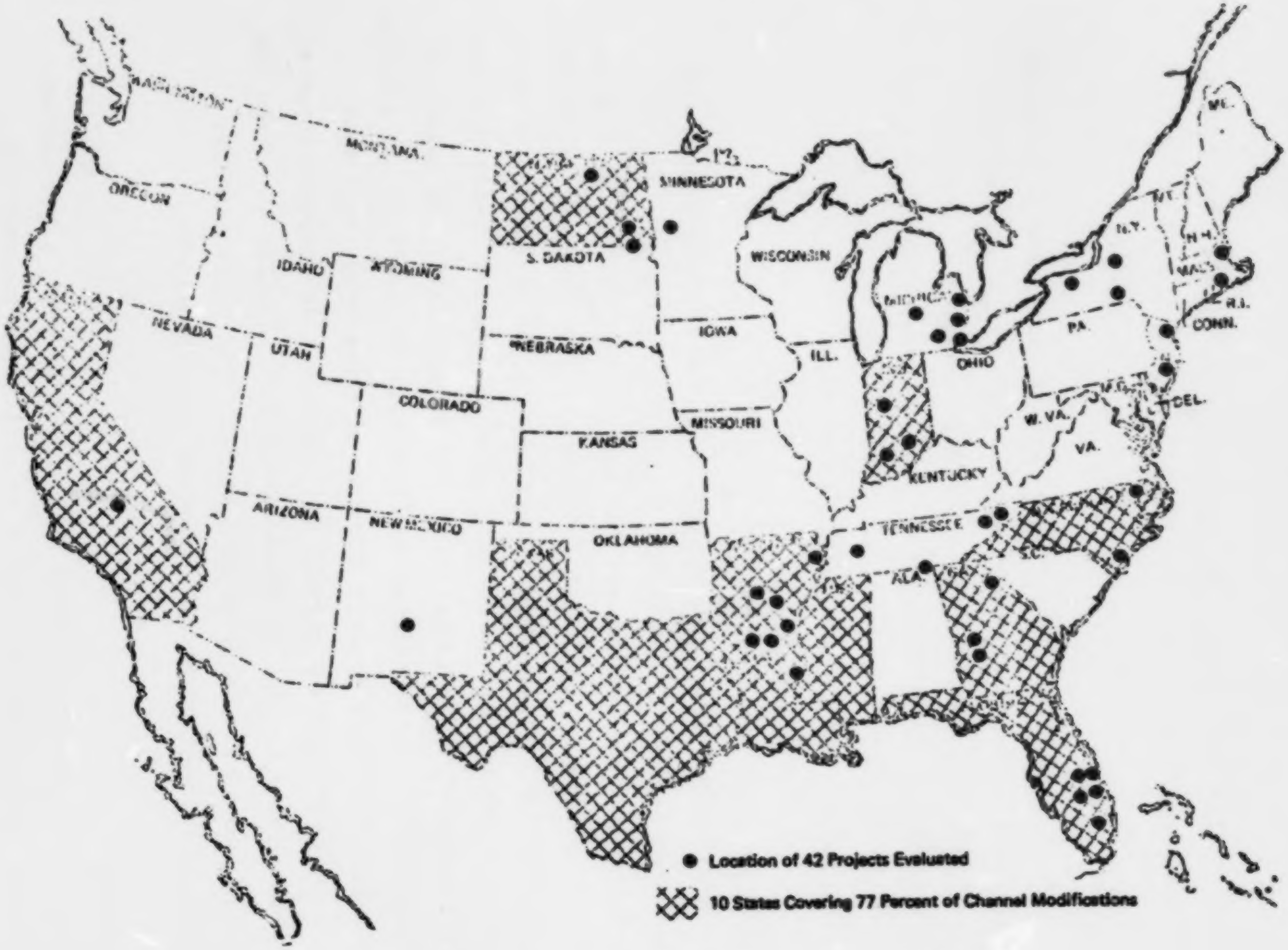

WASHINGTON
OREGON
MONTANA
IDAHO
WYOMING
NEVADA
UTAH
COLORADO
ARIZONA
NEW MEXICO
S. DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
MINNESOTA
IOWA
MISSOURI
WISCONSIN
ILL.
MICHIGAN
OHIO
KENTUCKY
TENNESSEE
ALA.
S.C.
W. VA.
VA.
PA.
N.Y.
VT.
N.H.
MASS.
R.I.
CONN.
DEL.
ME.
● Location of 42 Projects Evaluated
▨ 10 States Covering 77 Percent of Channel Modifications

Exhibit 164. Location of Projects Covered $^{(A-2)}$

Exhibit 165. CHANNEL MODIFICATIONS EVALUATED (A-2)
(Miles)

Project	Total	Natural Stream	Ditch Rehabilitation
Oliver Springs	1.2	1.2	1.5
North St. Lucie River	1.5		1.5
Yantic River	1.5	1.5	
Owasco Outlet	1.8		1.8
Mt. Clemens	2.4		2.4
Batvaia	3.7	3.7	
Palmetto Creek	3.9	3.9	
Sevierville	4.0	4.0	
River Rouge	4.2	2.0	2.2
Corning	4.3	3.5	0.8
North Nashua	4.5		4.5
Muskrat Creek	4.6		4.6
Town Bank	4.7		4.7
Little Wea Creek	8.6	3.6	5.0
Kings River	9.0	9.0	
Pine Bluff	9.6	7.6	2.0
Bois-de-Sioux	9.7		9.7
Red Run Drain	11.0		11.0
Ft. Pierce Farms	11.5		11.5
Bull Creek	13.5	13.5	
Elk Creek	14.0	2.5	11.5
Pequest River	15.0	10.0	5.0
N. Branch Mill Creek	15.7	0.1	15.6
Caw Caw Swamp	16.5	12.2	4.3
N. Branch Forest River	19.3	9.0	10.3
Wild Rice Creek	24.7	5.0	19.7
Taylor Creek	29.9	5.9	24.0
Fish Bayou	35.0	5.0	30.0
N. Fork Broad River	36.0	16.0	20.0
Crow Creek	44.2	40.2	4.0
Chicot, Desha, Drew	45.8		45.8
Prairie Creek	46.6		46.6
Wild Rice River	50.9	26.9	24.0
Kissimmee	58.0	18.0	40.0
Beech River	70.3	48.0	22.3
Bayou Bartholomew	74.0	70.0	4.0
Grady-Gould	88.0	2.2	85.8
North Tensas	102.4	24.0	78.4
Ahoskie-Cutawhiskie	119.6	49.7	69.9
S. Florida Conservancy District	120.0		120.0
Middle Rio Grande	186.0	186.0	
Boeuf-Tensas-Bayou Macon	972.4	593.0	379.4
Total	2299.5	1177.2	1122.3

one of the responsible or interested Federal agencies such as S.C.S., Corps of Engineers, TVA, or Bureau of Reclamation. Each evaluation consisted of a general orientation and project briefing session, a field survey of the project area, and a wrap-up session which was usually held at a place and time which would encourage local-interest participation. The field evaluations consisted of the local groups as well as the professional observations of the investigators who note: "Our professional observations may or may not be accepted as a part of the body of factual data, but we have exercised extreme caution to avoid surmise and conjecture. After all, professional observations are a part of any assessment."

Parameters -

Besides presenting all relevant descriptive material concerning each site, including location, topography, soil, land use and ground cover, climate/rainfall, history, and configuration of the proposed project itself, assessments were made on the physical effects such as wetland drainage and land-use changes, cutoff of oxbows and meanders, watertable changes and stream recharge, erosion, sedimentation, channel maintenance, downstream effects, aesthetics, and other specified purposes. Economic considerations and alternatives to construction were also considered. A biological evaluation was also done for each site by the Academy of Natural Sciences (Philadelphia, Pa.)

Again, as the investigators point out, much of the factual data of the field reports consist of professional observations. Because of the nature of this data, there is little quantitative information presented that is based on measurement of water quality or hydraulic parameters. Exhibit 166 summarizes the types of possible physical effects at each of the 42 project sites.

Exhibit 166. SUMMARY OF EFFECTS RELATIVE TO SIGNIFICANT ISSUES (A-2)

Project listing (from smallest to largest size of channel works)	Channel miles	Channel Works of Relatively Minor Significance to the Issue of							Channel Works of Uncertain Significance to the Issue of							Channel Works of Relatively Pronounced Significance to the Issue of						
		Wetland Drainage	Hardwood Clearing	Cut-off Meanders	Groundwater & Recharge	Erosion & Sedimentation	Downstream Effects	Aesthetics	Wetland Drainage	Hardwood Clearing	Cut-off Meanders	Groundwater & Recharge	Erosion & Sedimentation	Downstream Effects	Aesthetics	Wetland Drainage	Hardwood Clearing	Cut-off Meanders	Groundwater & Recharge	Erosion & Sedimentation	Downstream Effects	Aesthetics
Oliver Springs	1.2	X	X	X	X	X	X								X							
North St. Lucie River	1.5	X	X	X	X	X	X	X														
Yantic River	1.5	X	X	X	X	X	X															X
Owasco Lake	1.8	X	X	X	X	X	X	X														
Mt. Clemens	2.4	X	X	X	X	X	X	X														
Batavia	3.7	X	X	X	X	X	X	X														
Palmetto Creek	3.9	X	X	X	X	X	X	X														
Sevierville	4.0	X	X	X	X	X	X															X
River Rouge	4.2	X	X	X	X	X	X															X
Corning	4.3	X	X	X	X	X	X	X														
North Nashua	4.5	X	X	X	X	X	X	X														
Mu krat Creek	4.6	X	X	X	X	X	X	X														
Town Bank	4.7	X	X	X	X	X	X	X														
Little Wea Creek	8.6	X	X	X	X	X	X	X														
Kings River	9.0	X	X	X	X		X						X		X							
Pine Bluff	9.6	X	X	X	X			X					X	X								
Bois-de-Sioux	9.7	X	X	X	X	X	X	X														
Red Run Drain	11.0	X	X	X	X	X		X						X								
Ft. Pierce Farms	11.5	X	X	X	X	X	X	X														
Bull Creek	13.5	X	X	X	X		X						X									X
Elk Creek	14.0	X	X	X	X		X	X					X									
Pequest	15.0	X	X	X	X	X	X	X														
N.Branch Mill Creek	15.7	X	X	X			X	X				X	X									
Caw Caw Swamp	16.5			X			X			X		X	X			X						X
N.Branch Forest River	19.3	X	X	X	X	X	X								X							
Wild Rice Creek	24.7		X	X	X	X	X	X	X													
Taylor Creek	29.9			X		X				X		X		X	X	X						
Fish Bayou	35.0		X	X		X	X	X	X			X										
N.Fork Broad River	36.0		X	X	X		X		X				X		X							
Crow Creek	44.2				X				X	X				X				X		X		X
Chicot, Desha, Drew	45.8			X				X					X			X	X		X		X	
Prairie Creek	46.6			X	X		X	X	X	X			X									
Wild Rice River	50.9	X								X		X		X				X		X		X
Kissimmee	58.0									X		X	X	X		X		X				X
Beech River	70.3				X		X			X						X		X		X		X
Bayou Bartholomew	74.0					X										X	X	X	X			X
Grady-Gould	88.0			X				X					X			X	X		X		X	
North Tensas	102.4			X									X		X	X	X		X		X	
Ahoskie-Cutawhiskie	119.6						X			X		X	X			X		X				X
S.Florida Conservancy	120.0	X	X	X	X	X	X	X														
Middle Rio Grande	186.0			X			X			X			X			X			X			X
Boeuf-Tensas-Bayou Macon	972.4												X			X	X	X	X		X	X

APPENDIX E: EFFECTS OF DREDGING AND IN-WATER CONSTRUCTION ON WATER QUALITY

General

This appendix presents summaries of seven case studies that contain data on several aspects of dredging, including: impact of release of dredge materials on certain water quality parameters; effects of dredging on phosphate concentration in a lake; concentration of chemical constituents (ions, suspended solids, and other chemical compounds) in a lake before, during, and after dredging. None of the case studies pertains directly to in-water construction operations other than dredging.

Case 28. San Pablo Bay - Dredge Spoils Disposal Monitoring

Source -

Environmental Quality Analysts, Inc., "Dredge Spoils Disposal Monitoring San Pablo Bay - February 5, 1974," for U. S. Army Corps of Engineers San Francisco District, March 1974. (A-51)

Purpose -

To monitor the depletion of dissolved oxygen content of the receiving water and its recuperation period after the disposal of dredge spoil into the water.

Site Description -

Exhibit 167 shows the location of the disposal area and the survey site in San Pablo Bay, San Francisco.

Study Method -

Six loads of dredge spoil of 2,700 cubic-yard capacity each were released at a distance of 30 to 60 meters (first three) and 150 to 125 meters (second three) from a survey vessel anchored in the disposal area for monitoring purposes. Water quality parameters were monitored in situ at different depths downstream at five-second intervals. At various times during the monitoring period, samples were also taken for laboratory determination of dissolved oxygen and calibration of the electronic monitors being used.

Parameters Measured -

1. Dissolved oxygen
2. Turbidity and light transmittance
3. Specific electrical conductivity

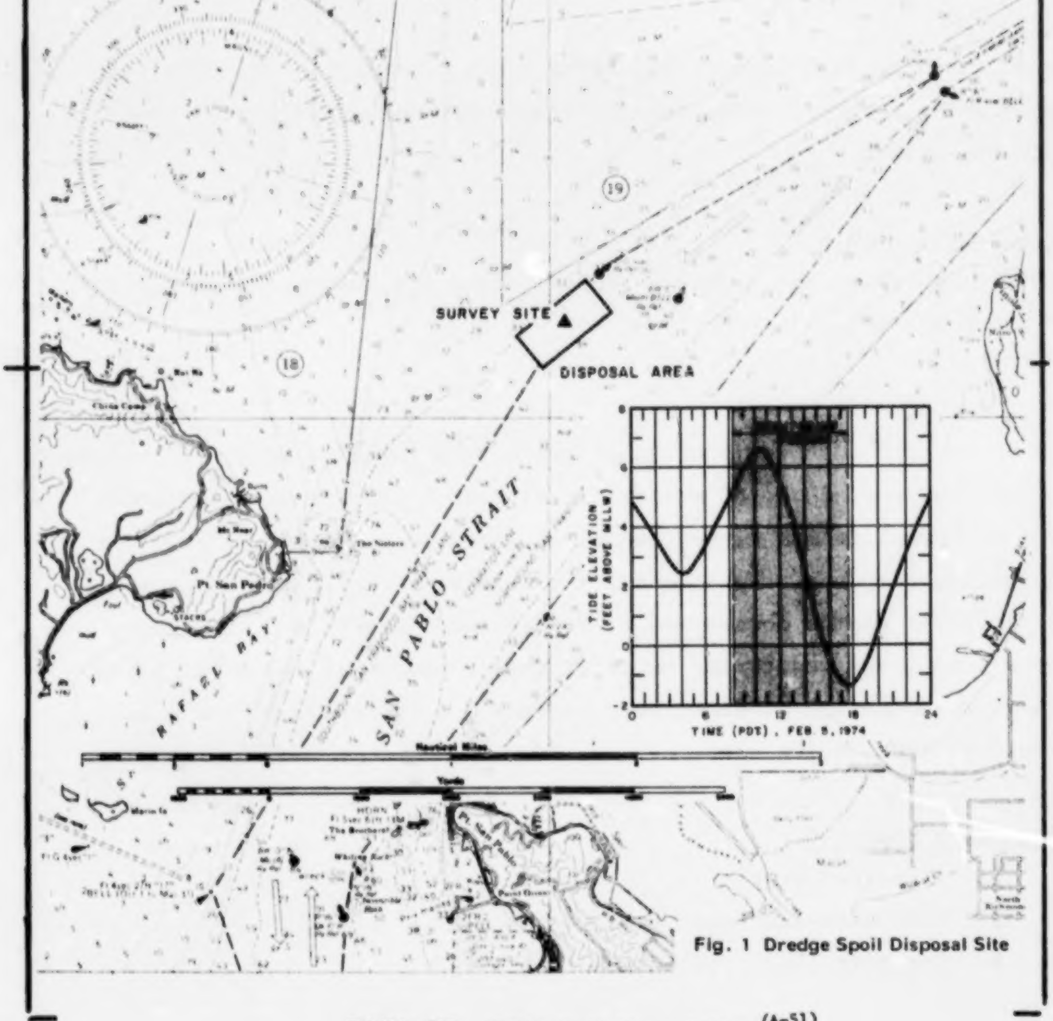

SAN PABLO BAY
SURVEY SITE
DISPOSAL AREA
SAN PABLO STRAIT
RAFAEL BAY
Pt San Pedro
The Sisters
TIDE ELEVATION (FEET ABOVE MLLW)
TIME (PDT), FEB 5, 1974
0
6
12
18
24
-2
0
2
4
6
8
Nautical Miles
Yards

Fig. 1 Dredge Spoil Disposal Site

Exhibit 167. Dredge Spoil Disposal Site (A-51)

4. Temperature
5. Depth
6. pH
7. Current speed and direction

Exhibit 168 presents the method of measurement, accuracy, and recording method for each parameter. The first six are important from this study viewpoint.

Time Frame -

January 18, 1974 to February 5, 1974

Results -

Exhibits 169 through 171 present the monitored results of the six-dredge spoil releases.

The following were the background values during the sampling period of various releases.

Release Number	D.O.	Salinity	pH	Temperature	Light Transmittance
1	8.2 mg/l	21.4 ppt	8.1	10.7°C	-
2	8.6 mg/l	22.0 ppt	8.1	10.7°C	1 percent
3	8.6 mg/l	22 to 23 ppt	8.2	10.7	1 to 2 percent
4	8.3 mg/l	22.6 ppt	8.2	10.6	5% decreasing to 1%
5	8.9 mg/l	17.8 ppt	8.1	10.4	1 percent
6	9.4 mg/l	8.5 ppt	8.0	10.0	1 percent

Exhibit 168. PARAMETERS MEASURED DURING DREDGE SPOIL DISPOSAL MONITORING (A-51)

Parameter	Method of Measurement	Accuracy	Indicating and Recording Methods
Dissolved Oxygen[a]	Auto-Temperature Compensated Polarographic Gold/Silver Electrode	± 1% Full Scale, ± 0.2 Parts Per Million	Digital, Printed Paper Tape ASCII Coded Mylar Tape
Turbidity, Light[c] Transmittance	25-cm Path XMS Transmissometer	± 1% Full Scale	Digital, Printed Paper Tape ASCII Coded Mylar Tape
	10-cm Path Hydro Products Model 612 Transmissometer	± 2% Full Scale	
Specific Electrical Conductivity	Five-Electrode Guarded Kelvin Cell	± 0.02 millimho/cm	Digital, Printed Paper Tape ASCII Coded Mylar Tape
Temperature[b]	Transistor Probe	± 0.1 C ± 0.01 C Resolution	Digital, Printed Paper Tape ASCII Coded Mylar Tape
Depth	Pressure Transducer	± 1% Full Scale, ± 1 Foot	Digital, Printed Paper Tape ASCII Coded Mylar Tape
pH	Glass and Silver/Silver Chloride Electrodes	± 0.1 pH Unit ± 0.01 Unit Resolution	Digital, Printed Paper Tape ASCII Coded Mylar Tape
Current Speed and Direction	Ducted Current Meter	± 0.03 kt. and ± 5 Deg.	Analog Chart Paper Recorder

[a] Calibrated during survey using Winkler titration procedure.

[b] Temperature measuring systems are checked for accuracy with N.B.S. calibrated thermometers.

[c] The 25-cm transmissometer was used on the first run; the 10-cm unit was used on all other runs.

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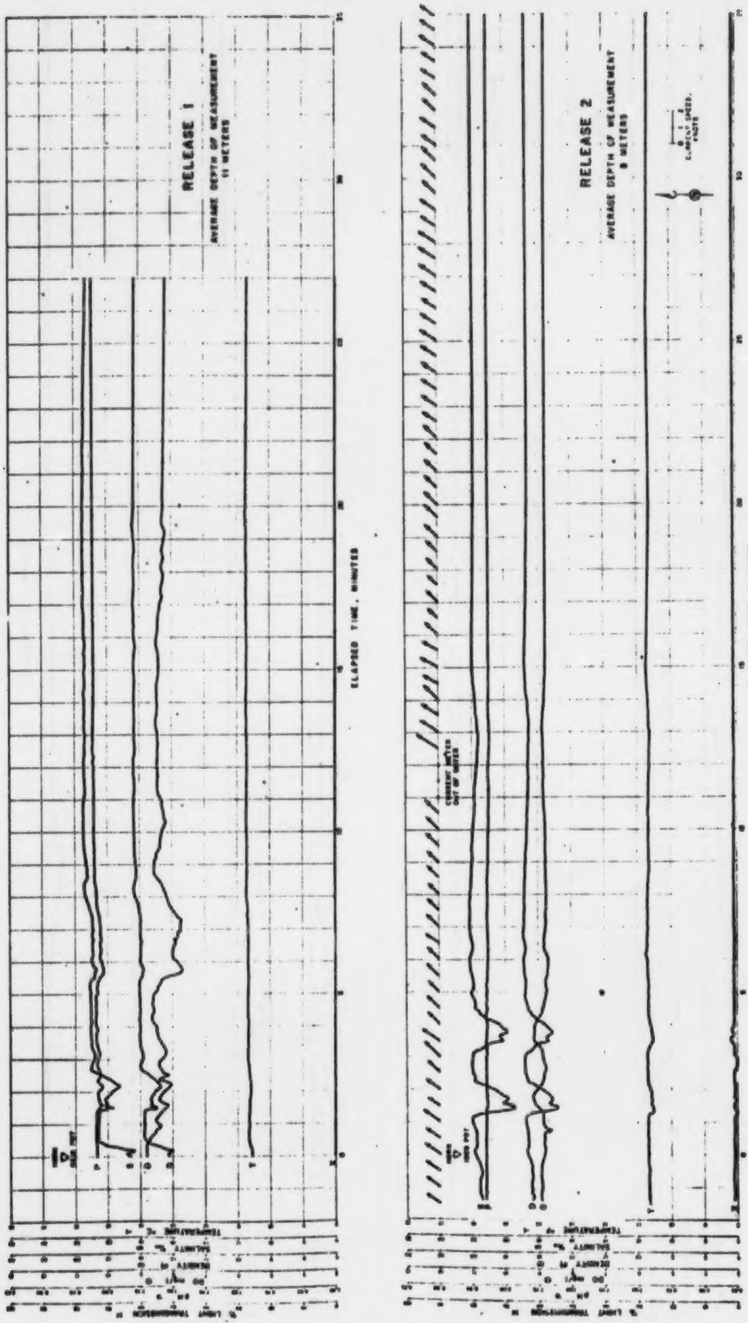

Exhibit 169. Receiving Water Parameters (A-51)
(Releases 1 and 2)

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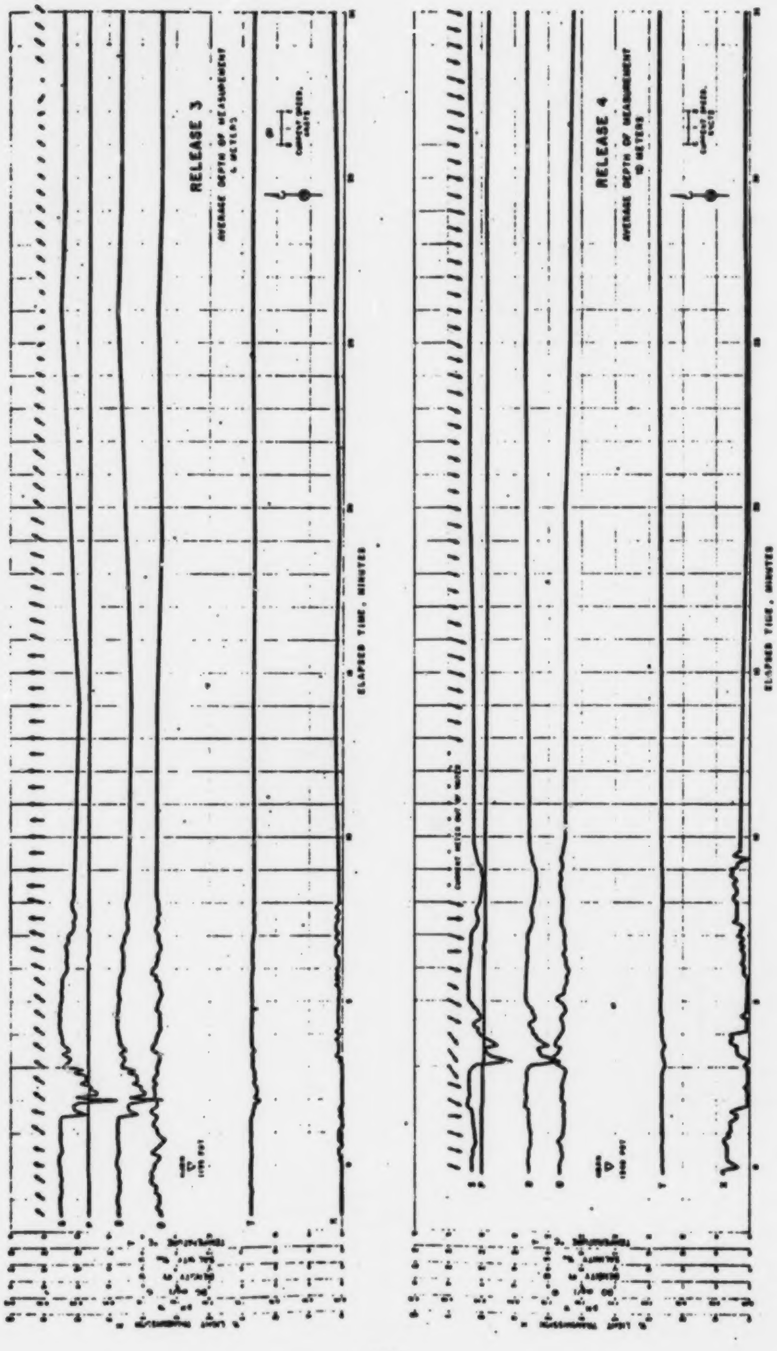

Exhibit 170. Receiving Water Parameters (A-51)
(Releases 3 and 4)

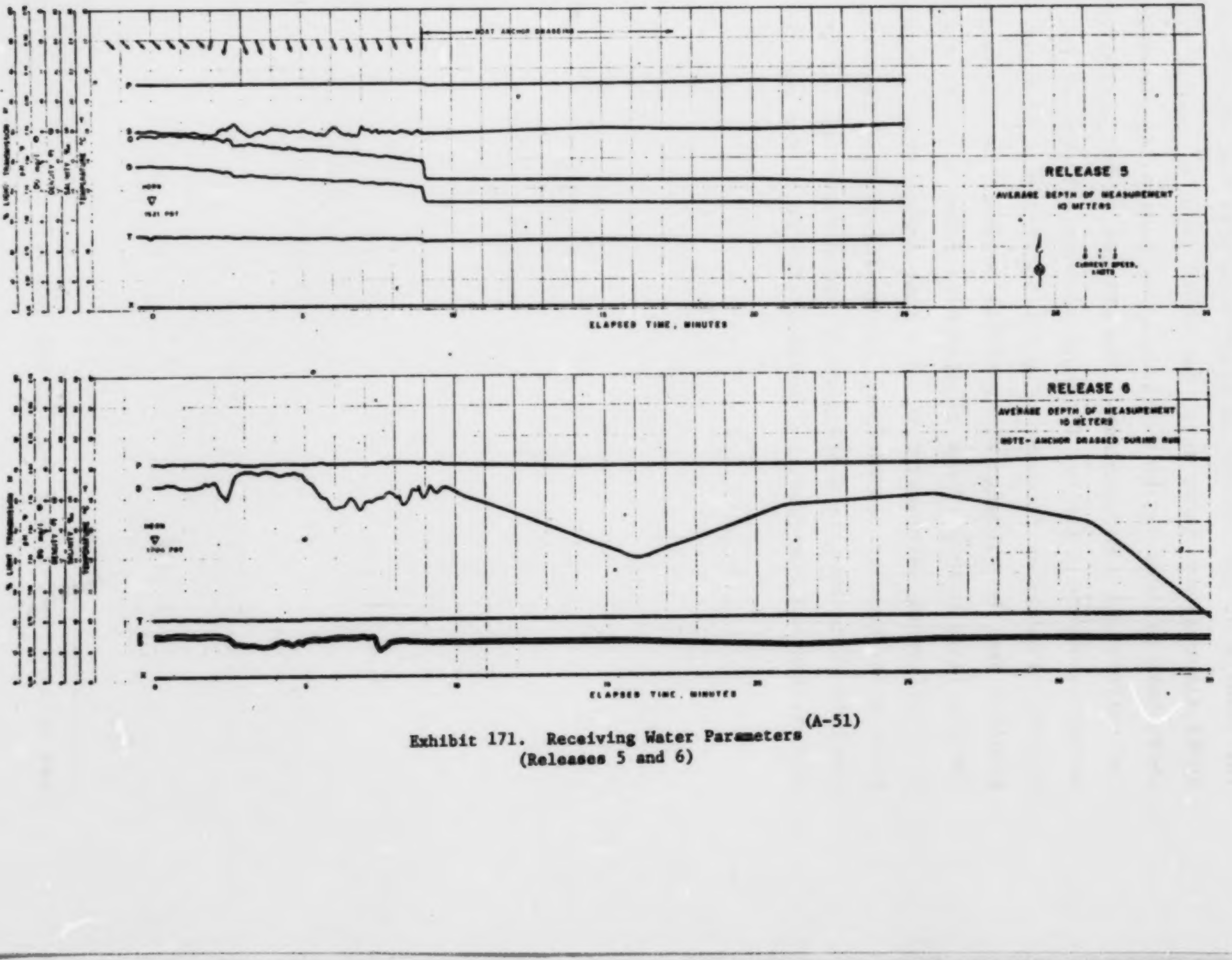

Exhibit 171. Receiving Water Parameters$^{(A-51)}$
(Releases 5 and 6)

Discussion -

The results of the referenced study show that the effects of dredge spoil disposal are short term, but other studies[*] reveal that even short term effects can be detrimental by destroying the spawning area and suffocating the organisms. The changes in the bottom geometry and bottom substrate after the disposed-of material settles can bring subsequent alterations in water velocity and current patterns, salinity gradient and the exchange of nutrients between the bottom sediments and the overlying water. These studies also point out that although there is insufficient information to show that dredge spoil disposal creates gross water quality degradation, enough information is available to conclude that there is a presence of and a potential for water quality degradation and the resultant adverse effects on the benthic community.

---

[*] See References 5-22 and 5-23 of Section V.

Case 29. Study of Dredged Material Disposal in San Francisco Bay

Source-

Brown and Caldwell, Inc., "Effects of Dredged Materials on Dissolved Oxygen in Receiving Water," Prepared for U. S. Army Corps of Engineers, Contract Number DACW07-73-0051, March 1973. (A-8)

Purpose -

To determine the effect of dredged-material disposal on dissolved oxygen concentrations in the receiving water, and to analyze the dredged sediments and their redox potentials in the disposal area.

Site Description -

Exhibit 172 shows location of the study area in San Francisco Bay south of Mare Island and at the lower end of the Napa River. The depth of the disposal area ranged from 50 to 60 feet.

Dredged-Material Characteristics -

Exhibits 173 and 174 describe the results of the analyses of sediment samples and their grain size distribution. The sediments were fine grained and moderately polluted, having high COD and redox potential sufficient to reduce sulfate contents to sulfide.

Study Method -

The study involved two days of field work. On each day six discharges of dredged material were observed. On the first day the capacity of discharge was 3000 cubic yards and on the second day 2600 cubic yards. The monitoring was done by two boats--one boat for the unaffected area and the other for the affected area. On each of the two field studies

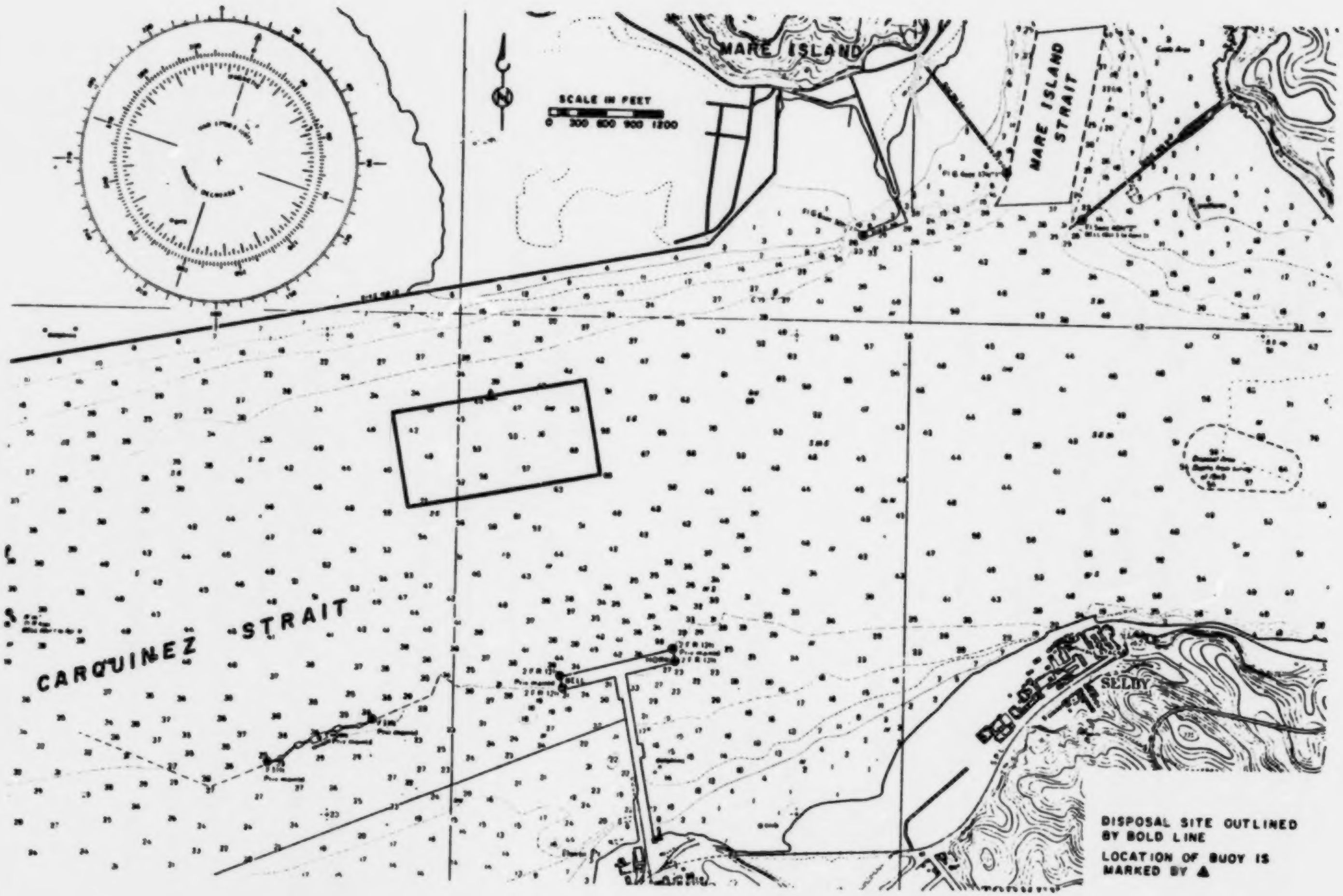
MARE ISLAND
MARE ISLAND STRAIT
SCALE IN FEET
0 300 600 900 1200
CARQUINEZ STRAIT
SELBY
DISPOSAL SITE OUTLINED BY BOLD LINE
LOCATION OF BUOY IS MARKED BY ▲

Exhibit 172. Study Area in San Francisco Bay (A-8)

Exhibit 173. RESULTS OF ANALYSES ON SAMPLES OF SEDIMENT FROM DREDGE HARDING, 29 JANUARY 1973

Sample	A	B	C
Total solids, percent wet wt	40	40	41
Volatile solids, mg/kg dry wt	85,000	84,000	85,000
Chemical oxygen demand, mg/kg dry wt	46,000	45,000	42,000
Total sulfides, S, mg/kg dry wt	14	90	150
Eh, volts	-0.47	-0.47	-0.47
pH	7.0	7.1	7.0

Samples A, B and C are replicates, results are in excellent agreement except for sulfides.

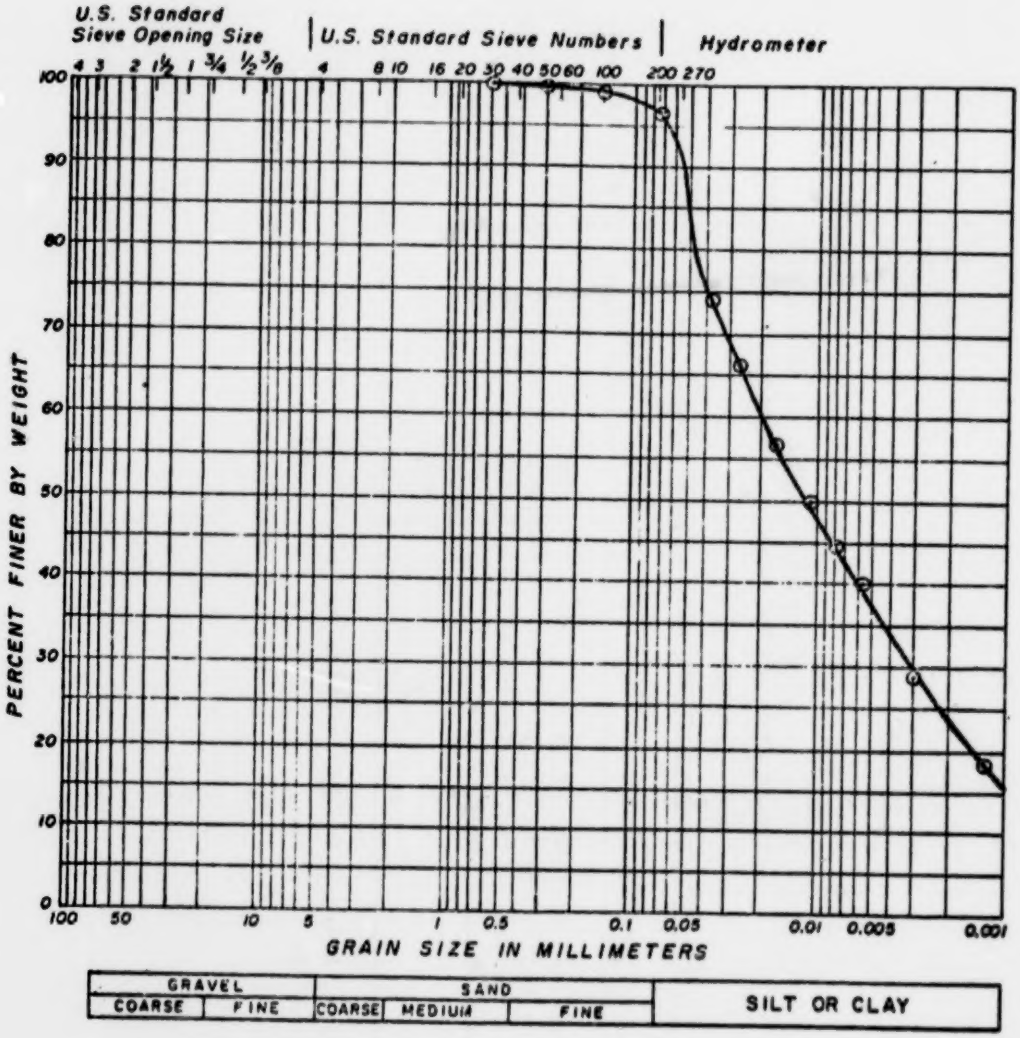

Exhibit 174. Grain Size Distribution of Sample From Dredge Harding Taken 29 January 1973(A-8)

dredge spoil samples were taken from the hopper for laboratory analyses. Divers also collected samples of water from the bottom for laboratory studies of redox potential and other parameters.

Parameters Measured -

1. Oxygen uptake
2. Sulfides
3. Grain size distribution
4. pH
5. Total solids
6. Volatile solids
7. Chemical oxygen demand
8. Temperature
9. Turbidity
10. Redox potential.

Time Frame -

January 17 and 29, 1973.

Results -

The first set of field data showed little variations with background data. Slight oxygen depressions were observed as depth increased. The reduced data are given in Exhibits 175 and 176 for oxygen concentrations. Exhibits 177 through 183 represent the reduced data for second set of observations.

From the results it appeared that the oxygen depressions were no longer than 3 or 4 minutes in duration. Turbulence was also noted immediately following dumping. Exhibit 184 shows the decreasing redox potential with depth measured for the sediment core samples.

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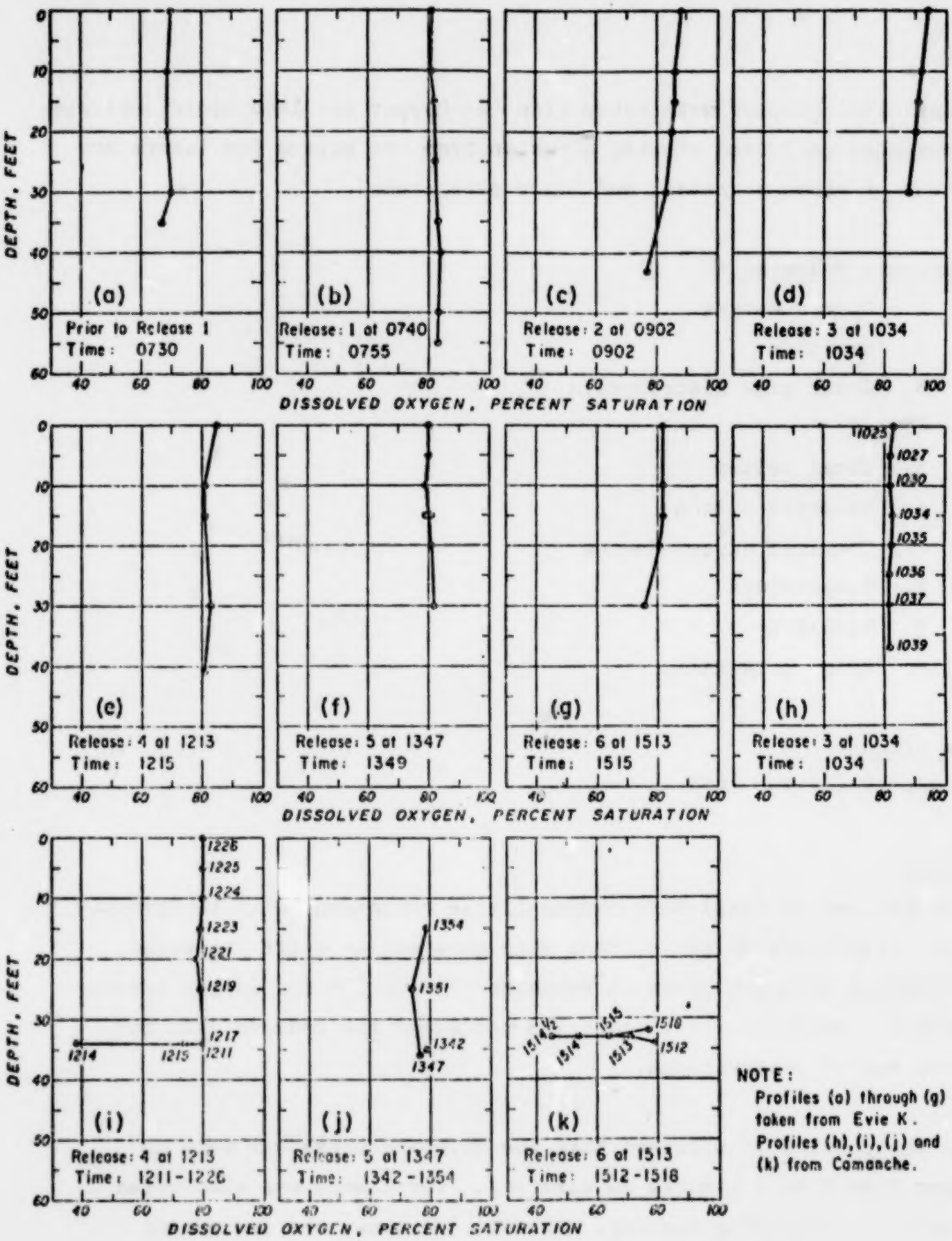

NOTE:
Profiles (a) through (g) taken from Evie K.
Profiles (h), (i), (j) and (k) from Comanche.

Exhibit 175. Oxygen Values Observed During Releases by Biddle, 17 January 1973 (A-8)

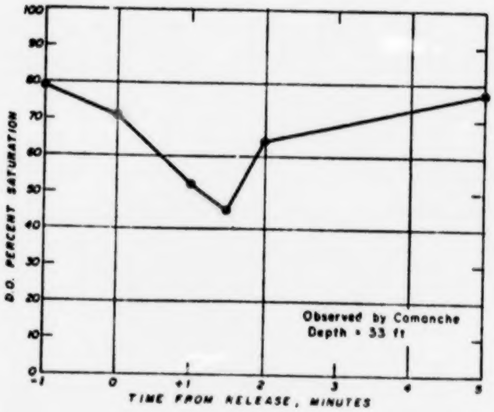

Exhibit 176. Oxygen Values Observed During Release Number 6 by Dredge Biddle, 17 January 1973 (A-8)

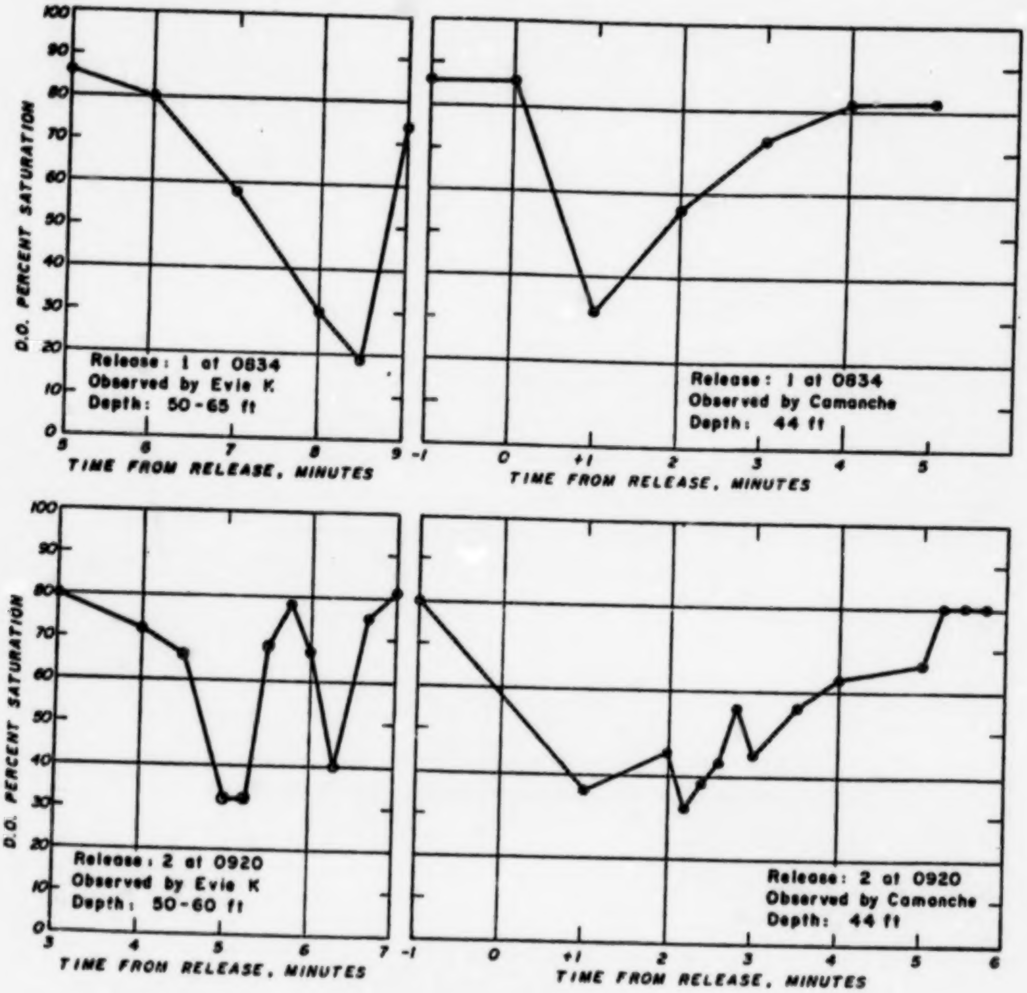

Exhibit 177. Oxygen Values Observed During First and Second Releases From Dredge Harding, 29 January 1973 (A-8)

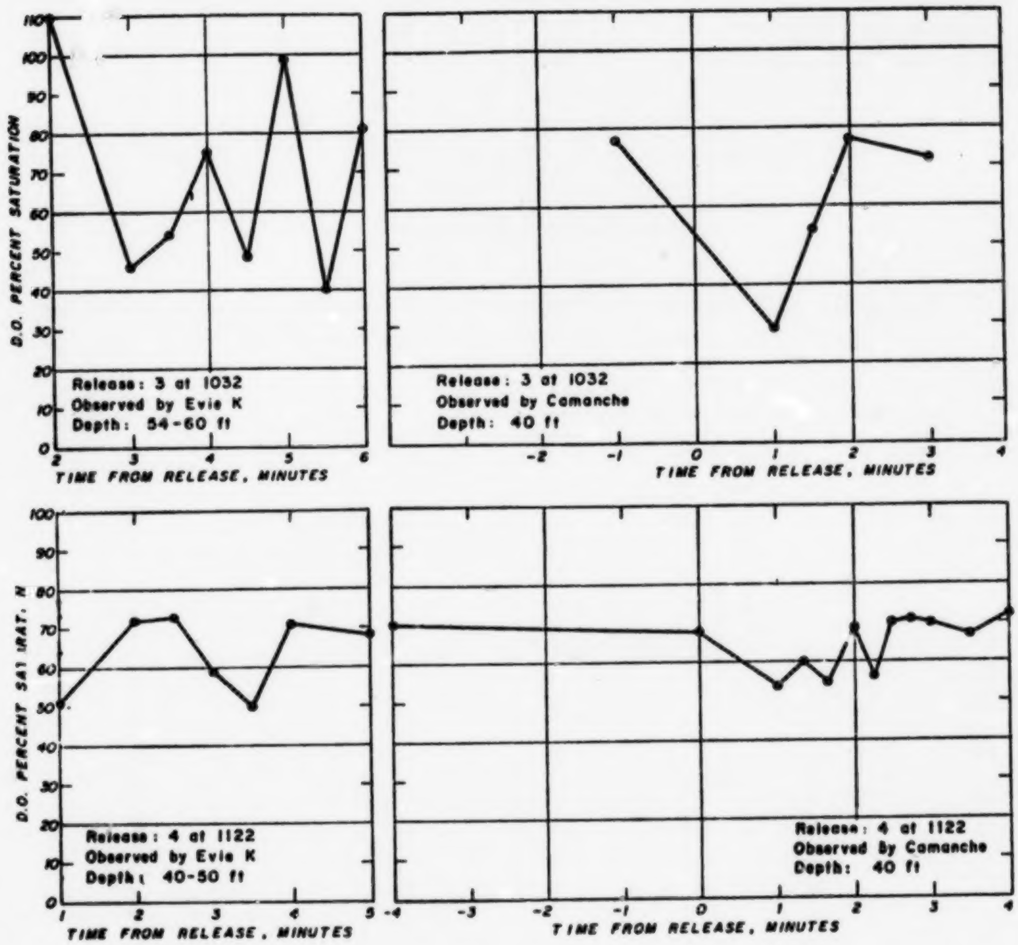

Exhibit 178. Oxygen Values Observed During Third and Fourth Releases from Dredge Harding 29 January 1973 (A-8)

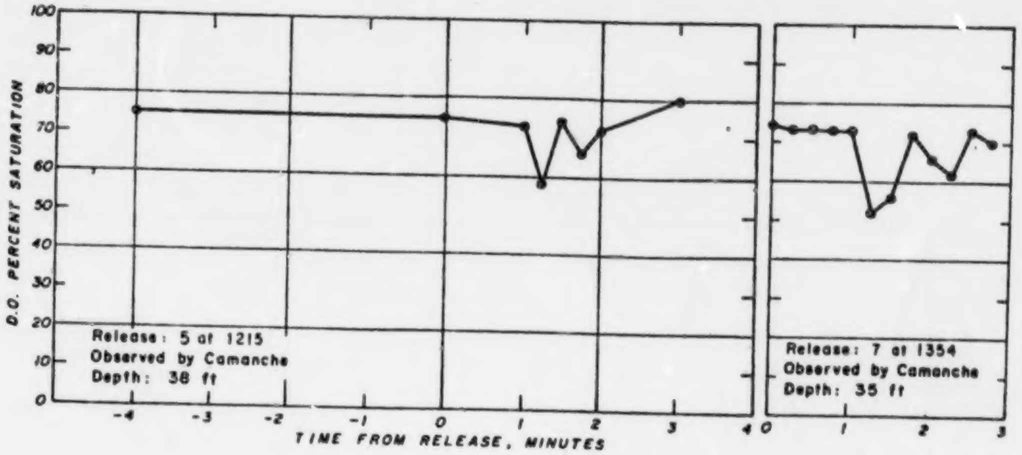

Exhibit 179. Oxygen Values Observed by R/V Camanche During Fifth and Seventh Releases by Dredge Harding, 29 January 1963 (A-8)

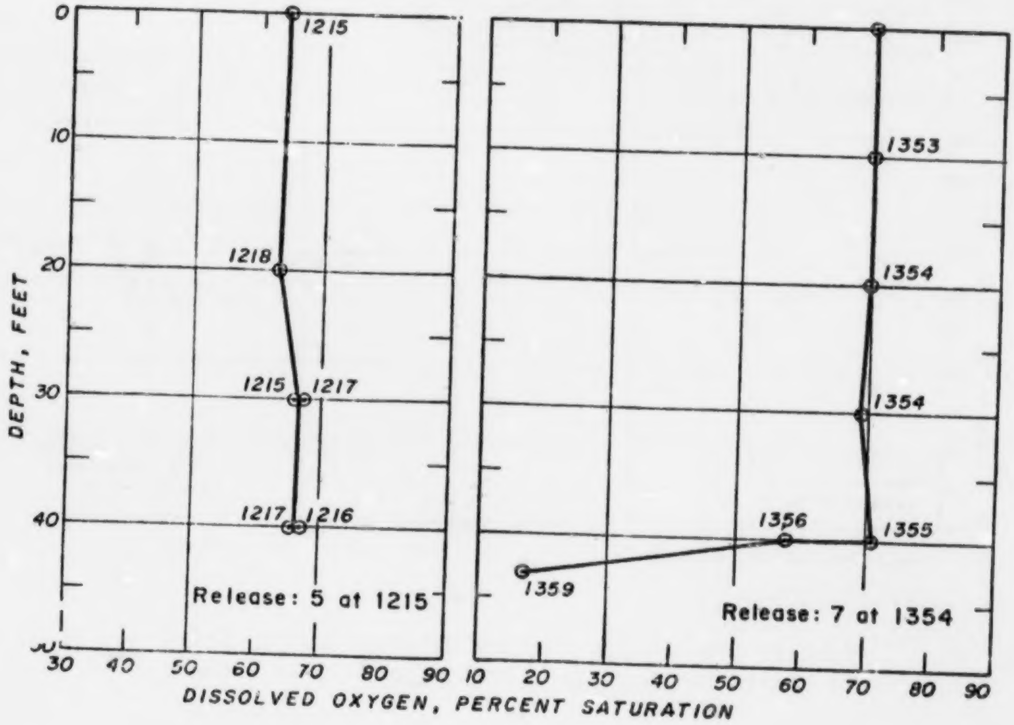

Exhibit 180. Oxygen Values Observed by R/V Evie-K During Fifth and Seventh Releases by Dredge Harding, 29 January 1973 (A-8)

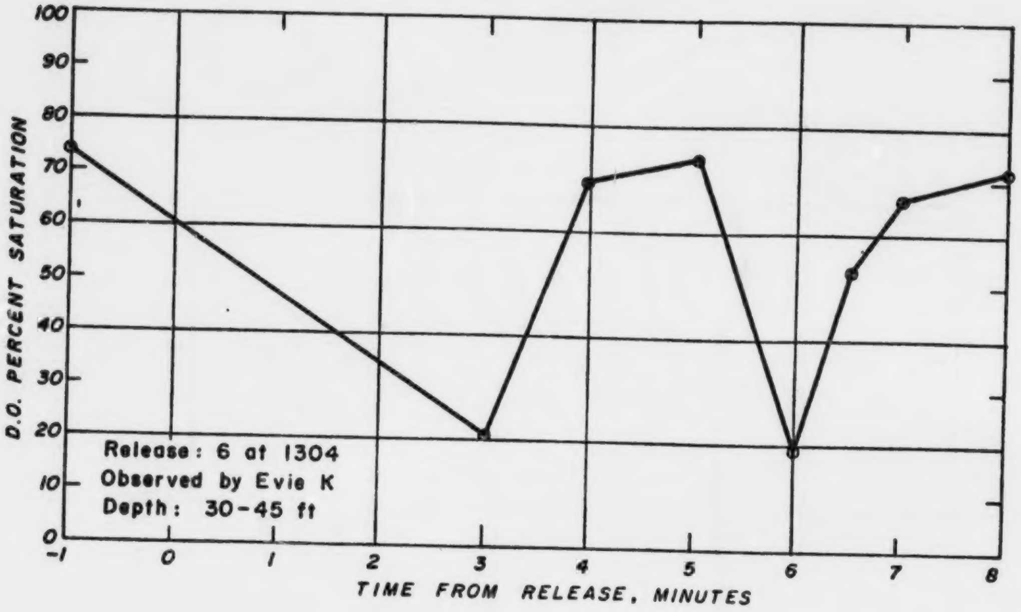

Exhibit 181. Oxygen Values Observed by R/V Evie-K During Sixth Release From Dredge Harding, 29 January 1973 (A-8)

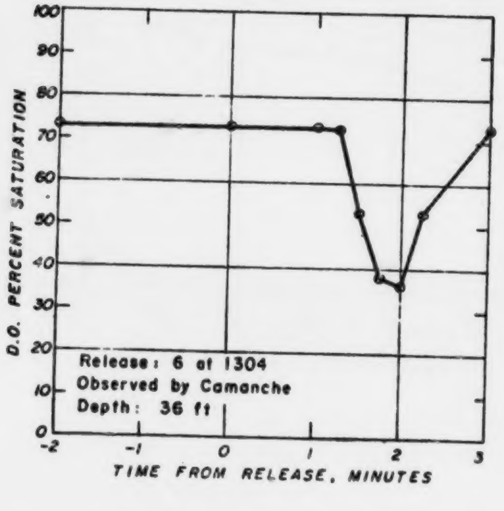

Exhibit 182. Oxygen Values Observed During Sixth Release by Dredge Harding on 29 January 1973 (A-8)

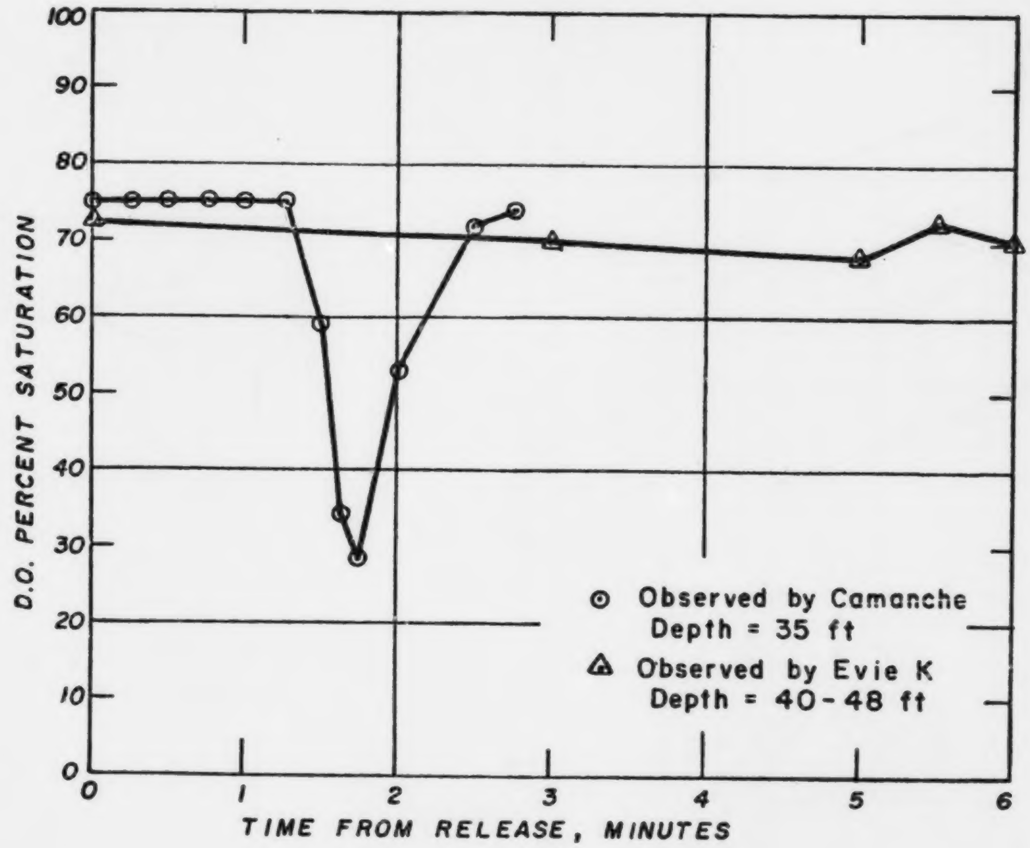

Exhibit 183. Oxygen Values Observed R/V Camanche During Sixth Release from Dredge Harding, 29 January 1973 (A-8)

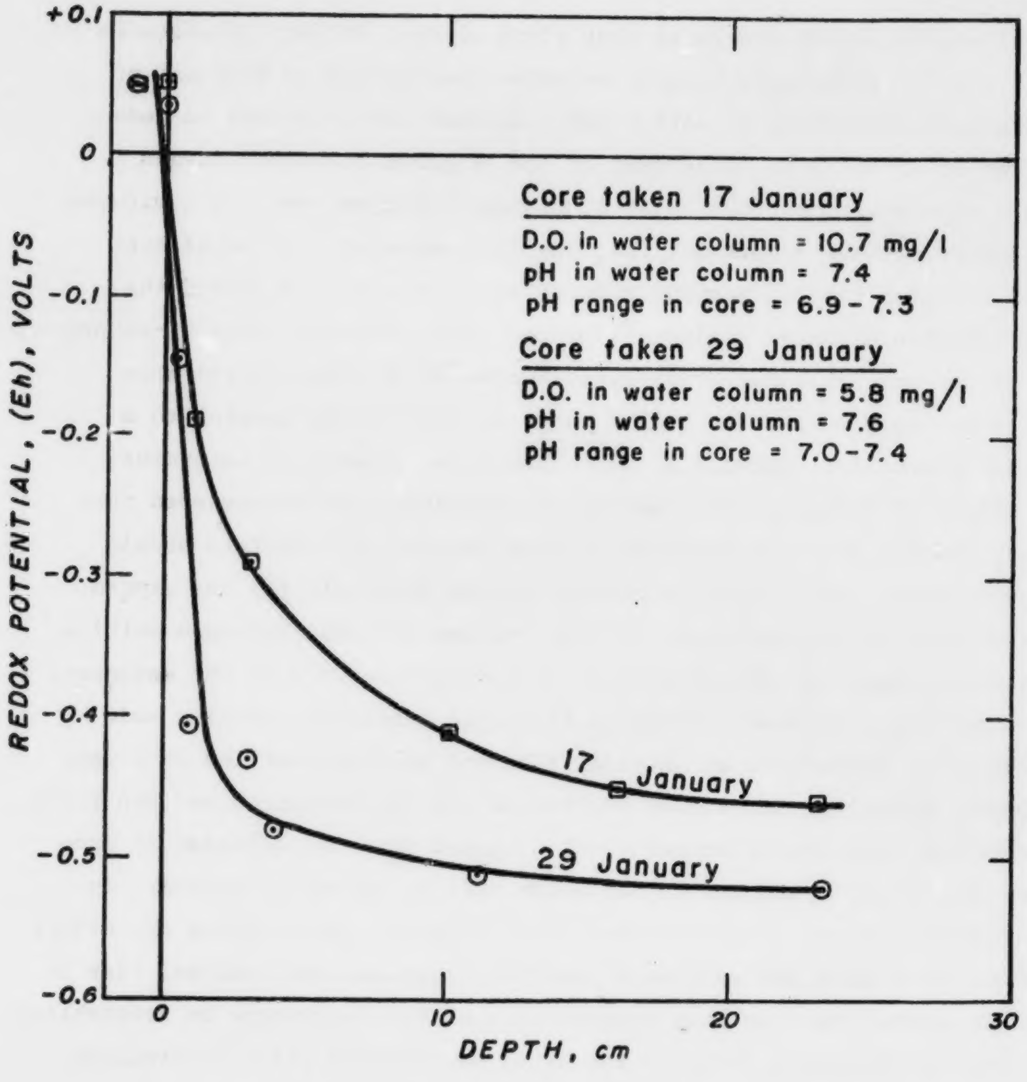

Exhibit 184. Redox Potential (Eh) Plotted Against
Depth of Measurement in sediment Cores Taken at Disposal Site (A- 8)

Discussion -

The referenced study concludes that given an area subject to adequate tidal mixing, short term effects on water quality due to disposal of moderately polluted spoil will occur. Depressions in oxygen concentration of up to 50 to 70 percent of the original dissolved oxygen levels can result near the point of disposal lasting for 3 to 4 minutes. The report further points out that the depression of D.O. is of such brief duration that no harmful effects could be assigned toward the deterioration of water quality. Various other studies, however, as pointed out in the San Pablo Bay Study (Case Number 28 of this report), show that even short term water quality degradations can be harmful to a benthic community. Servizi et al(A-46b) conducted studies to determine the effect of dredging and disposal of sediments, and recommended that before dumping polluted sediment in open waters, four factors should be considered: (a) turbidity created during disposal, (b) the oxygen demand (COD) of the sediment, (c) the release of toxic hydrogen sulfide during disposal, and (d) generation of hydrogen sulfide by the sediments after they have settled. Separate field and laboratory studies made by the U. S. Department of Interior Fish and Wildlife Service on hopper disposal operations in certain reaches of the San Francisco and San Pablo Bays reveal that the effectsof spoil disposal were not apparent in deep areas due to rapid changes in variables such as salinity; however, in other areas, it was concluded that spoil disposal and dredging operations reduced the number and species of benthic organisms and demersal fish to such an extent that for some species it took several months to reestablish the species diversity index to the level as observed prior to dredging.

Case 30. Effects of Dredging on the Nutrient Levels and Biological Populations of a Lake

Source -

Constance L. Churchill, et al. Effects of Dredging on the Nutrient Levels and Biological Populations of a Lake, Brookings Water Resources Institute, South Dakota State University, August 1972.(A-9)

Purposes -

1. To determine the change and rate of change of nutrient levels due to dredging.
2. To determine the effects of these nutrient level changes on the biological populations of the lake.

Site Description -

Lake Herman is located in Lake County, South Dakota, four miles southwest of the city of Madison. An undisturbed lake nearby, Lake Madison, was used as a control. Its average depth is 6-1/2 feet; its surface area approximately 1,350 acres. Lake Herman's watershed is 56 sq. mile, a large part of it cultivated corn and small grain fields. There are very few cabins or homes on the lake, although there is a popular state park on the eastern shore, as well as a number of other public and semipublic recreation areas.

Three major streams drain the watershed. These streams carry heavy sediment loads, especially during the spring thaws and after storms when large volumes of water are being transported. At present, 6 to 7 feet of silt have accumulated on the lake bottom. Exhibit 185 shows the confirguration of the lake and basin; Exhibit 186 shows the watershed.

The lake is iced over from mid-November through mid-April. There are frequent winter fish kills which have lately been prevented by coal

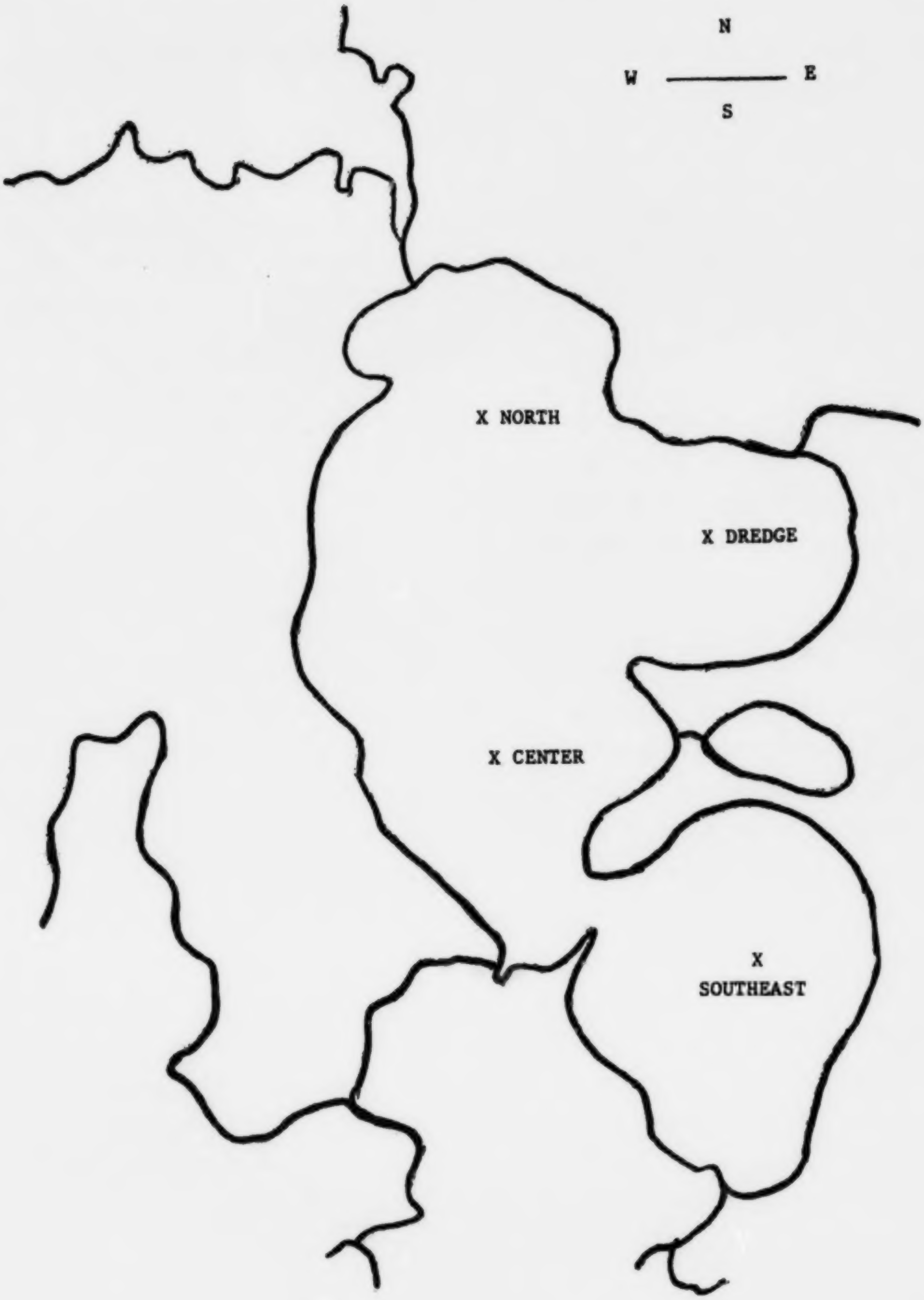
N
W
E
S
X NORTH
X DREDGE
X CENTER
X
SOUTHEAST

Exhibit 185. Lake Herman: Its Tributaries and Sampling Sites (A-9)

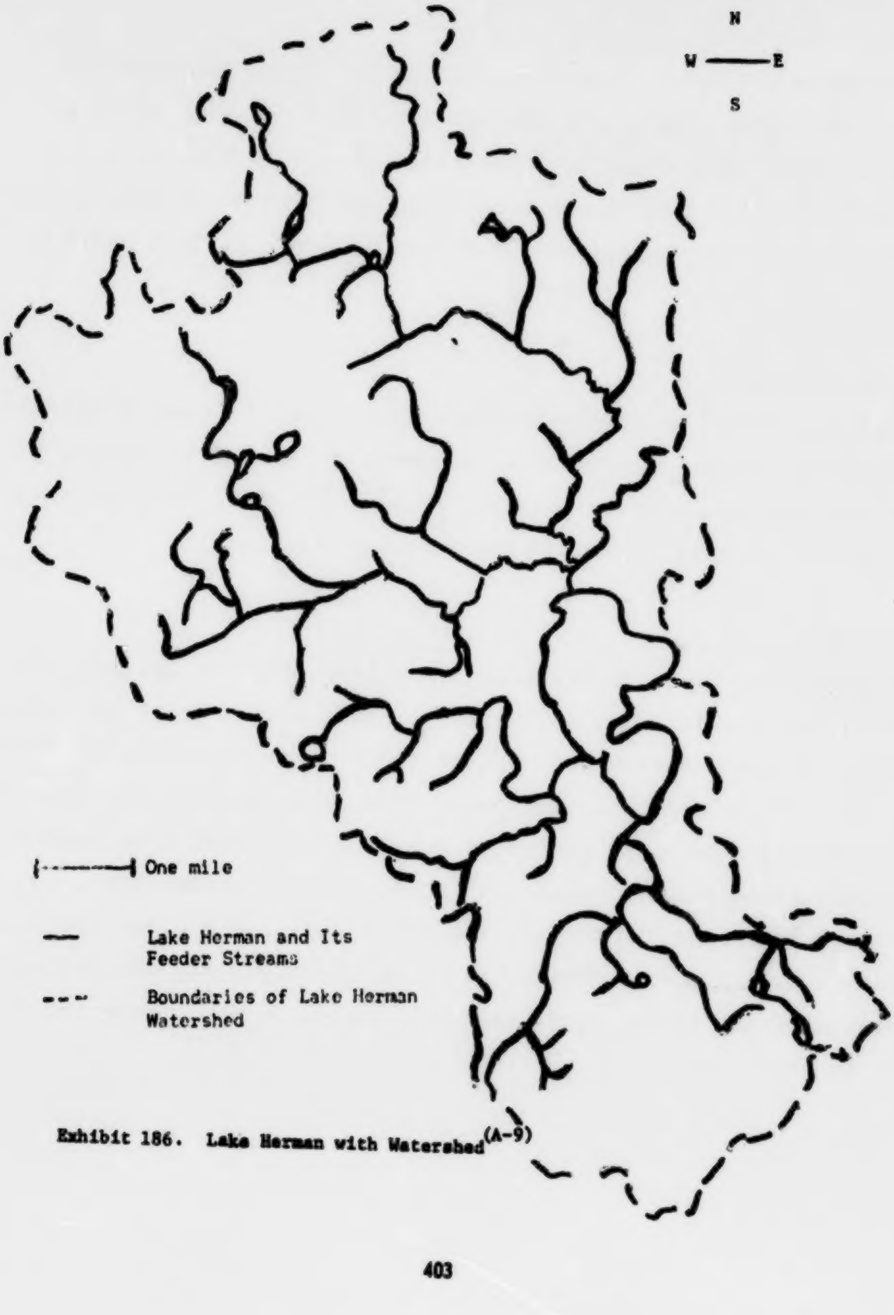
N
W
E
S
One mile
Lake Herman and Its Feeder Streams
Boundaries of Lake Herman Watershed

Exhibit 186. Lake Herman with Watershed$^{(A-9)}$

dusting and pumping. During the summers, the lake is often turbid due to disruption of the sediment surface by wind and wave action. Heavy algal blooms are common.

Time Frame -

Area landowners obtained a hydraulic dredge and began dredging the bottom in July 1970, continuing through October. The same schedule was used in 1971. The third dredging season began in May, 1972, and continued through the end of the monitoring period used in this study. The study project was carried out from July 1, 1969, through June 30, 1972.

Project Description -

The dredge pumped the sediments through a pipeline, floated on barrels, to a low lying area on the Northern Shore of the lake (see Exhibit 187). In the first two dredging seasons 52,000 cubic yards of sediment were moved from the lake and deposited in the disposal area.

Study Method -

Water samples were periodically taken from four sites on the lake before and during the dredging activities. These samples were analyzed for various chemical parameters and for the numbers and types of various algal and planktonic organisms. Pre-dredging data was compared with post-dredging data and both were compared with data from nearby Lake Madison. Samples were also collected from the dredge pipe, the silt deposit area, and the outlet from the deposit area where the water was returned to the lake. Another plase of the study was the biological analysis of the dredge spoil induced changes to the vegetation in the silt deposit area.

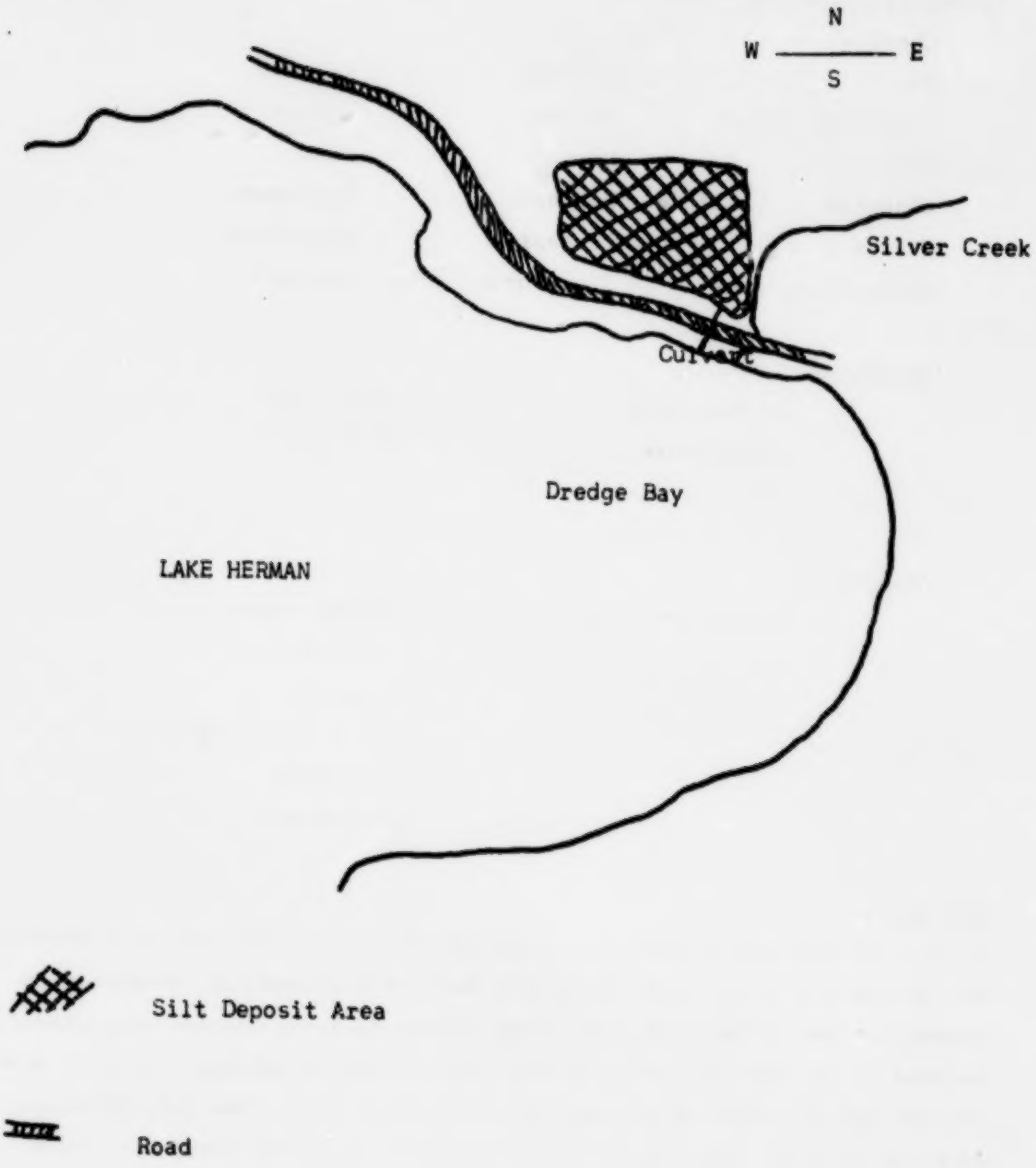
N
W
E
S
Silver Creek
Culvert
Dredge Bay
LAKE HERMAN
Silt Deposit Area
Road

Exhibit 187. Silt Deposit Area in Relation to Lake Herman (A-9)

Parameters Measured -

Chemical

pH
Dissolved oxygen
COD
Chloride
Silica
Ortho-Phosphorus
Ammonia
Nitrate
Nitrite
Hardness
Potassium
Phosphorus
Calcium
Copper
Iron
Magnesium
Manganese
Sodium

Physical

Conductivity
Temperature
Depth of Sample
Secchi Disk
Turbidity

Biological

Population densities

9 Green Algaes
2 Euglenoid
11 Diatoms
6 Blue Green Algaes
3 Copepoda
2 Cladocena

Results -

Of all the chemical parameters examined, the ones that were most affected by the dredging were total phosphate and ortho-phosphate. Predredging trends in Lake Herman and continuing trends in Lake Madison were characterized by phosphorus levels rising sharply in the spring, rapidly leveling out and fluctuating during the summer and fall. The initiation of dredging in 1970 resulted in a 300% increase in ortho-phosphate and a slightly greater increase in total phosphate between the end of June and October. Dredging was confined to the dredge bay, but phosphate increases were throughout the lake. This was due possibly to a thick growth of aquatic vegetation which cut this section off from the remainder of the lake. During the next winter, (1970-71), levels remained high. They peaked at the first spring runoff in February and declined to a level that was still higher than the previous year. Dredging again caused sharp rises which remained high throughout the dredging season. During the fall and winter, levels decreased to normal values. (See Exhibits 188 through 191.)

Other changes noted were a sharper rise of alkalinity in the spring, a slight, long range increase of silica and a greater increase in turbidity. In addition both hardness and calcium levels decreased. This was attributed to the formation of insoluble calcium phosphates that occurred due to the increased phosphate concentrations. (See Exhibits 192 through 195 .)

The changes in the biological activities that were observed were determined to be unrelated to the dredging activities. This observation and the very low nitrogen levels indicate that phosphorus is not the limiting nutrient in this lake. Exhibit 196 shows the total phytoplankton densitites in 1968 and 1970.

Examination of the samples taken from the disposal area provided some interesting results. The pH of the water returned to the lake from the disposal area averaged 7.86 while the lake water from which it was originally pumped (and to which it returned) averaged 9.06. The data is given in Exhibit 197.

The other major effect was that the ortho-phosphates in the spoils area were lower than in the lake (see Exhibit 198). At the initiation of dredging, the concentrations in the silt deposits were 75 percent of the lake values. This value decreased in the next four months while dredging continued to 10 percent of the value in the lake. The reason for this is not completely understood, but at least one author has suggested that the primary concentration of phosphorus is in the top few inches of sediment and that the disruption of this layer at the initiation of dredging caused the increase in lake phosphates, leaving the sediments with lower

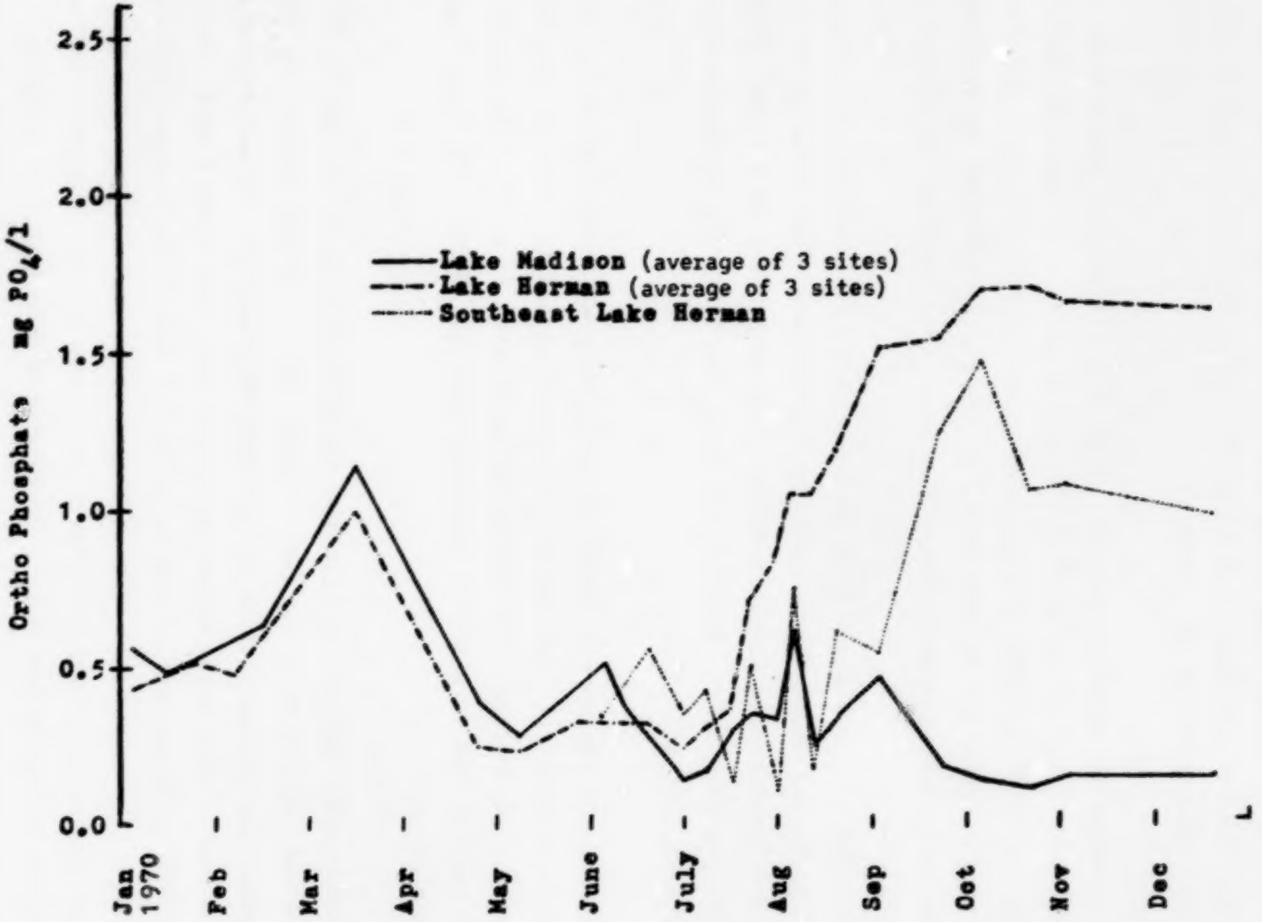

Exhibit 188. Orthophosphate Levels in Lakes Herman and Madison During 1970 (A-9)

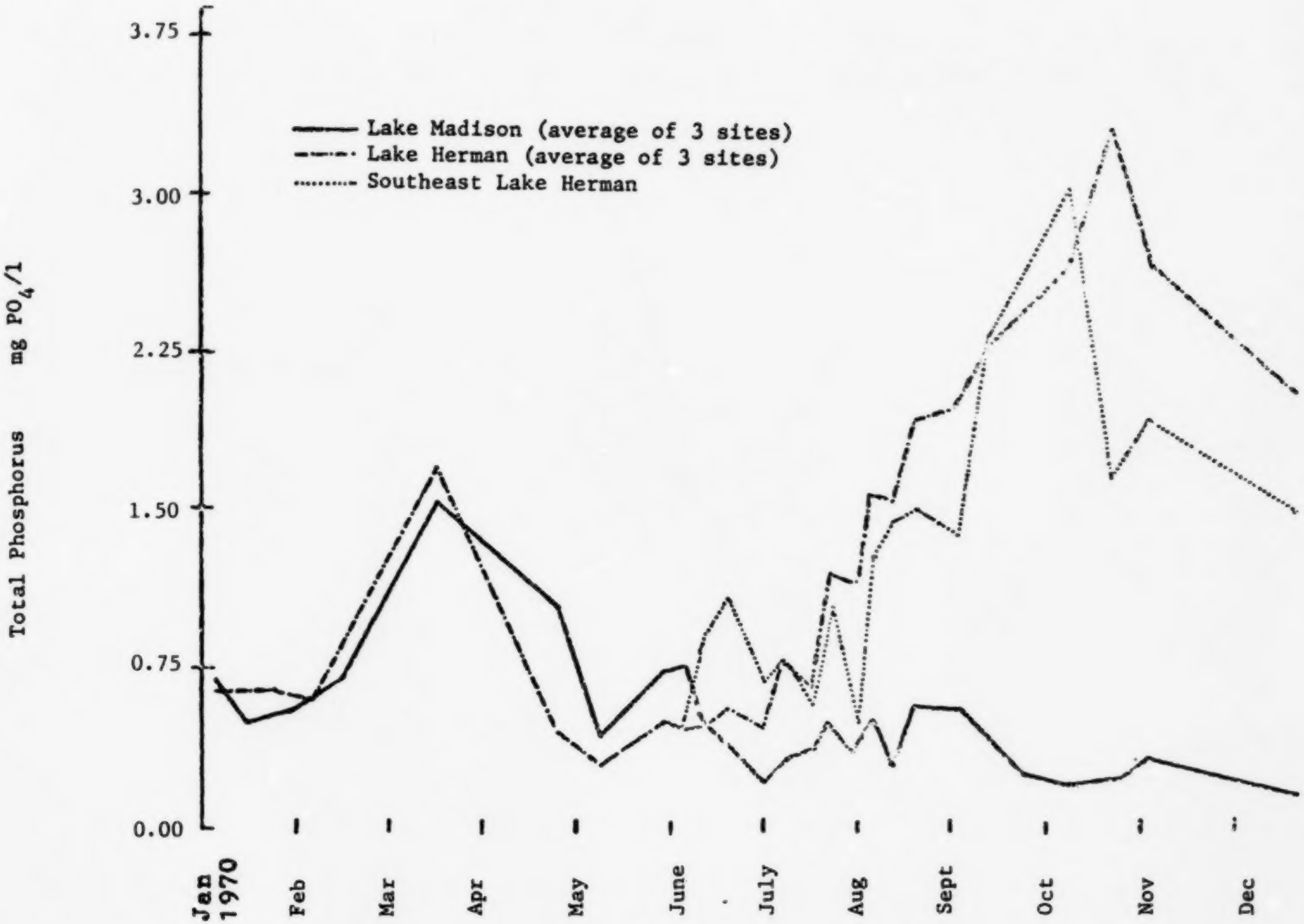

Exhibit 189. Total Phosphorus Levels in Lake Herman and Madison During 1970 (A-9)

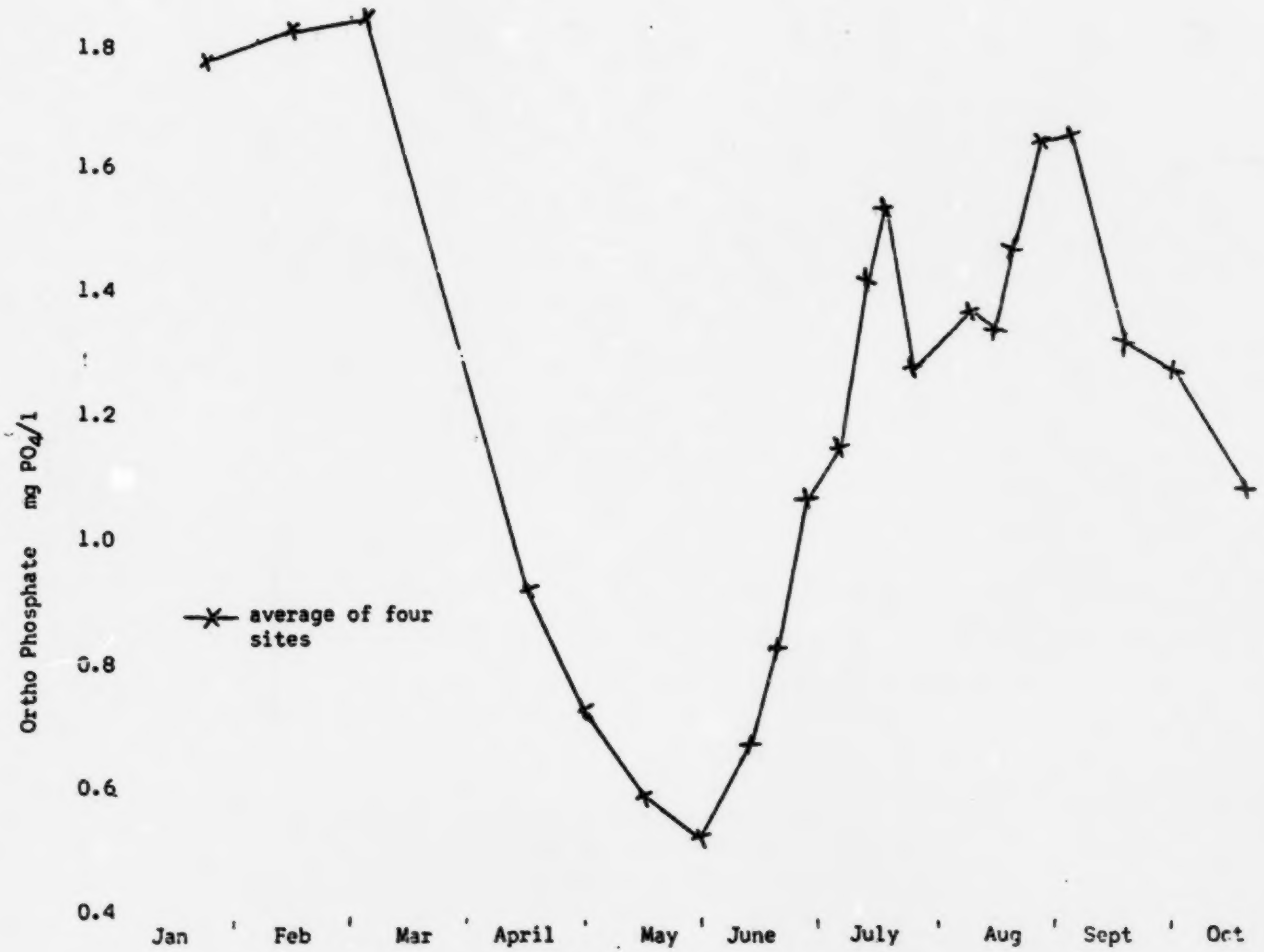

Exhibit 190. Orthophosphate Levels in Lake Herman During 1971 $^{(A-9)}$

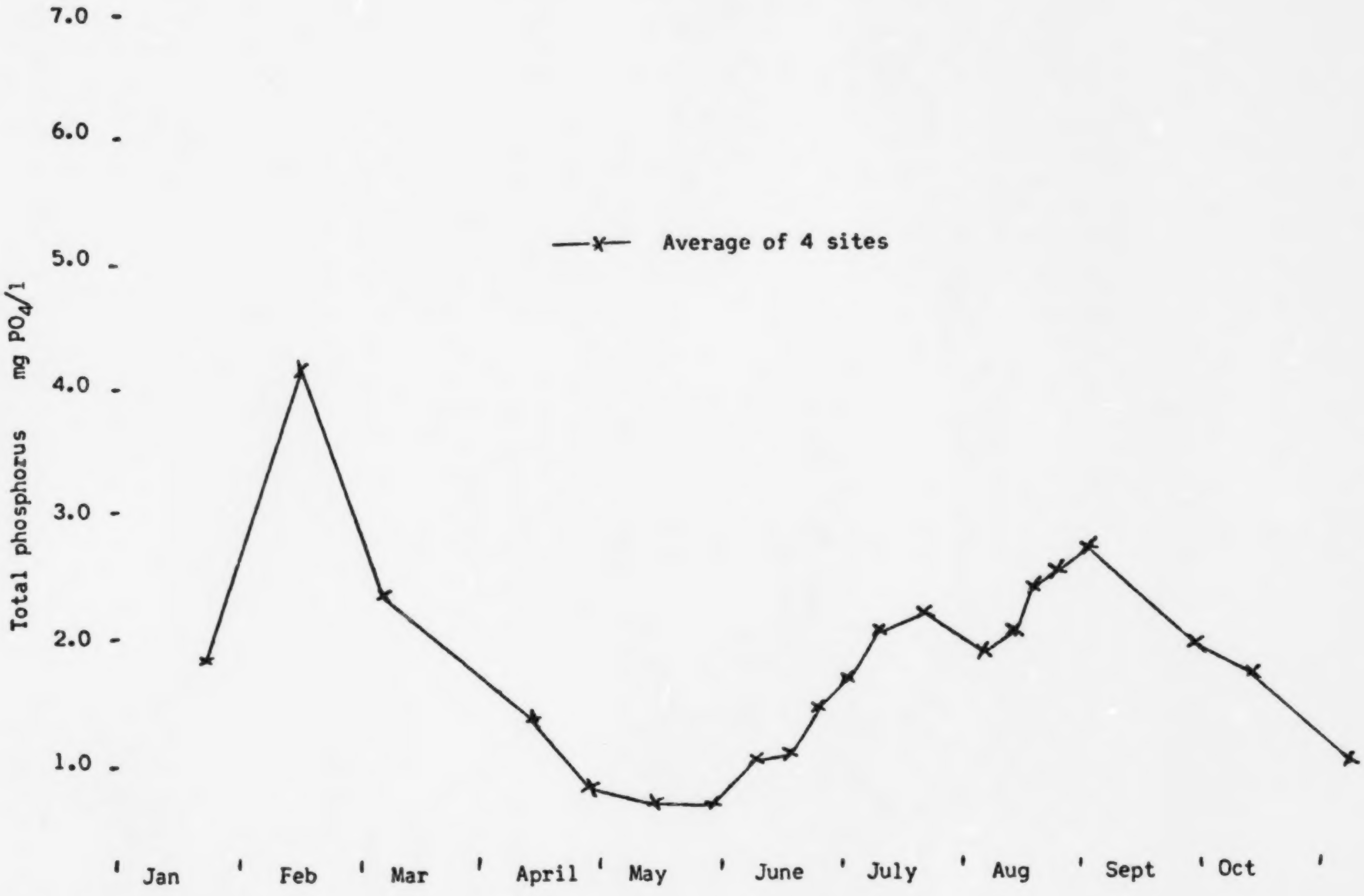

Exhibit 191. Total Phosphorus Levels in Lake Herman During 1971 (A-9)

Exhibit 192. ALKALINITY LEVELS IN LAKES HERMAN AND MADISON DURING 1970 (A-9)

Values are Averages for Multiple Sites; And Collections During Month

Month	Lake Madison Alkalinity (mg $CaCO_3$/l)	Lake Herman Alkalinity (mg $CaCO_3$/l)
January	177	212
February	183	224
March	94	46.1
April	144	144
May	158	151
June	174	157
July	168	140 (150)*
August	170	154 (161)*
September	170	170 (177)*
October	170	187
November	167	189
December	172	220

*Represent averages excluding southeast samples which were much lower than remainder of lake

Exhibit 193. SILICA AND TURBIDITY LEVELS IN LAKES HERMAN AND MADISON DURING 1970 (A-9)

Values are Averages for Multiple Sites and Collections During Month

Month	Lake Madison Silica (mg SiO_2/l)	Lake Herman Silica (mg SiO_2/l)	Lake Madison Turbidity (Jackson Units)	Lake Herman Turbidity (Jackson Units)
January	4.38	10.2	--	--
February	5.12	22.8	--	--
March	5.84	6.57	25	29
April	0.69	12.7	23	25
May	3.14	10.6	16	15
June	11.6	11.0	13	14
July	22.7	14.0 (15.8)*	25	27.8
August	29.2	20.4 (22.7)*	24	30.4
September	29.9	24.0 (24.8)*	14.4	33.1
October	23.7	21.8	14.5	23.2
November	18.4	16.6	14.2	22.5
December	19.3	19.7	18.6	21.6

*Represent averages excluding southeast samples which were much lower than remainder of lake.

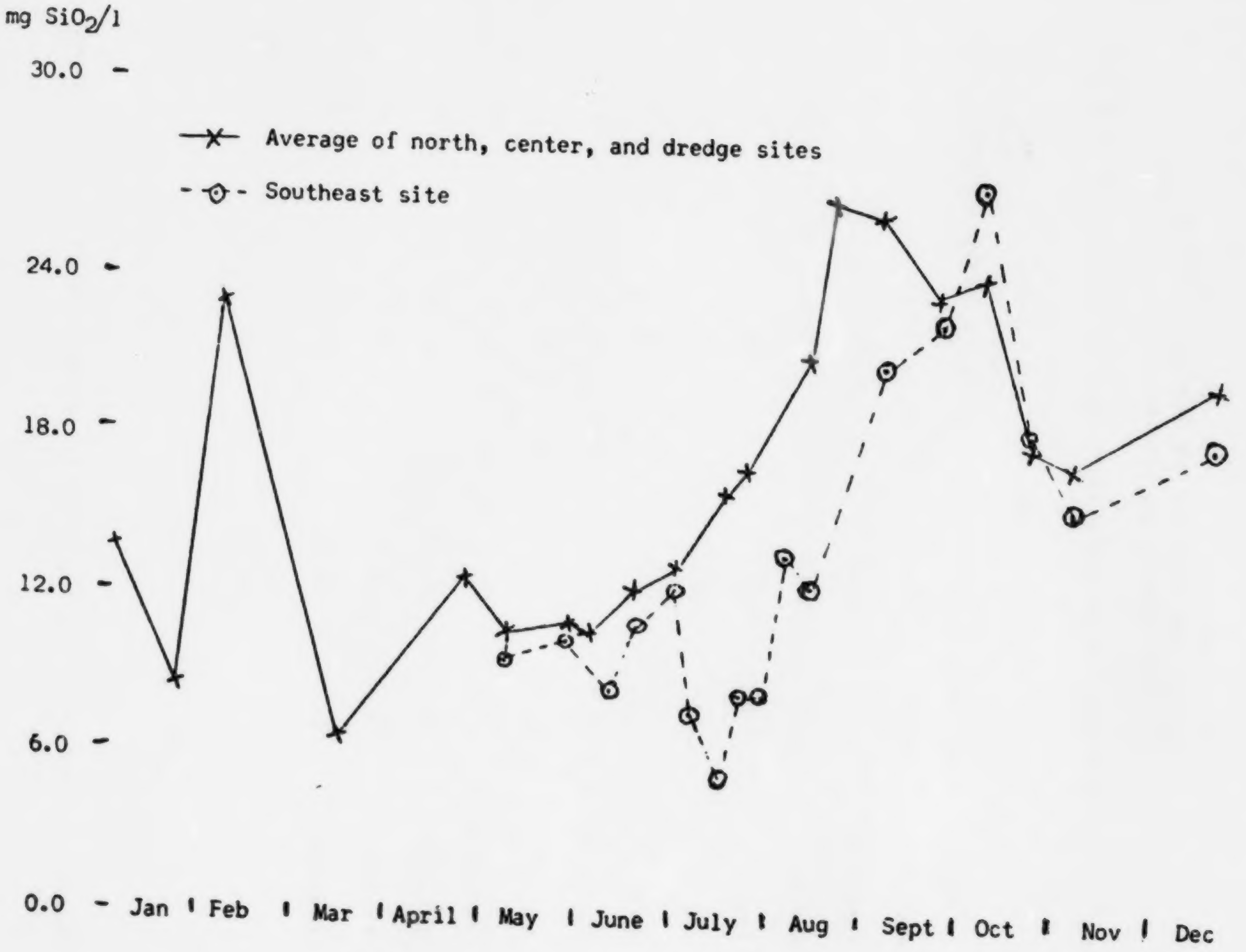

Exhibit 194. Silica Levels in Lake Herman During 1970 (A-9)

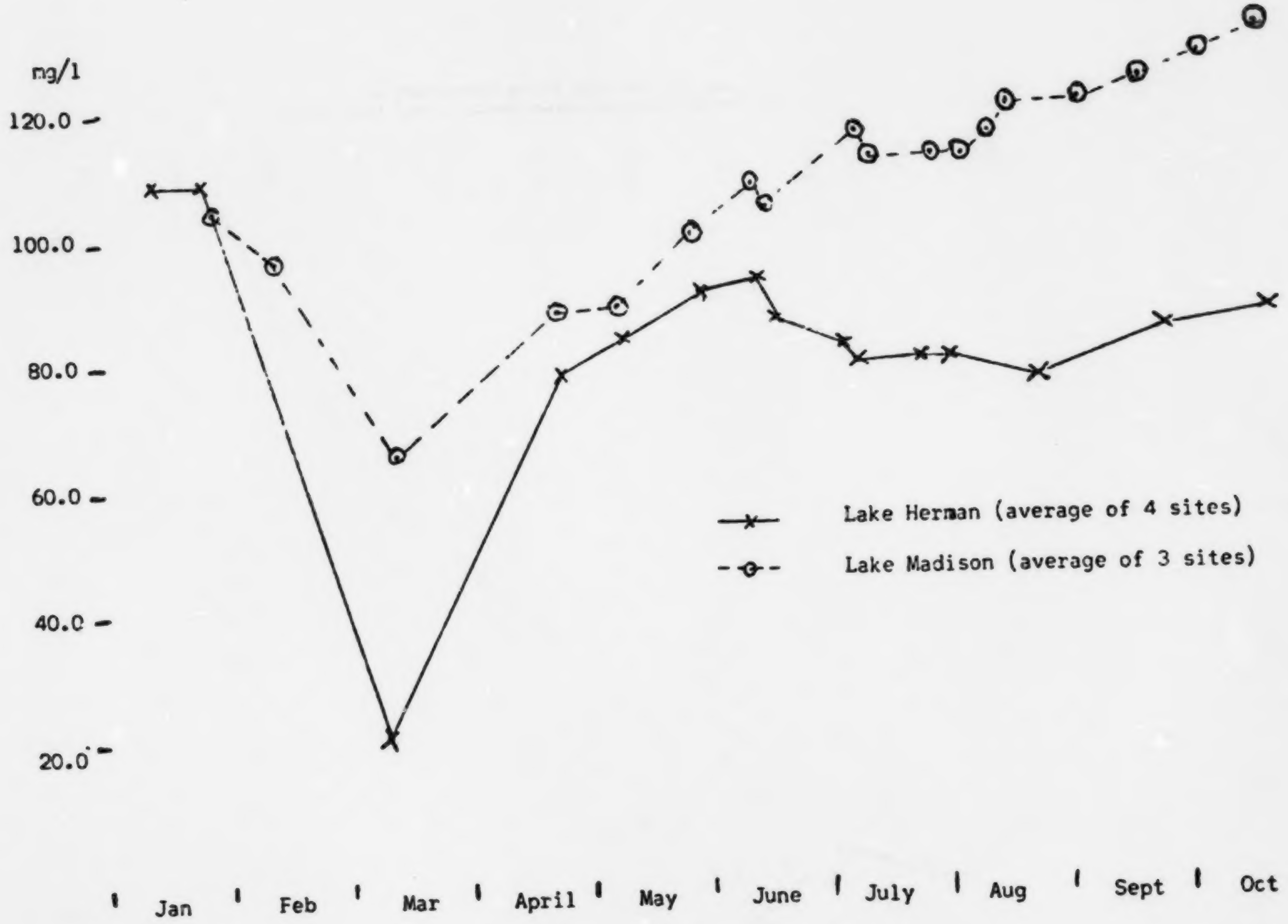

Exhibit 195. Calcium Levels in Lake Herman
and Madison During 1970 (A-9)

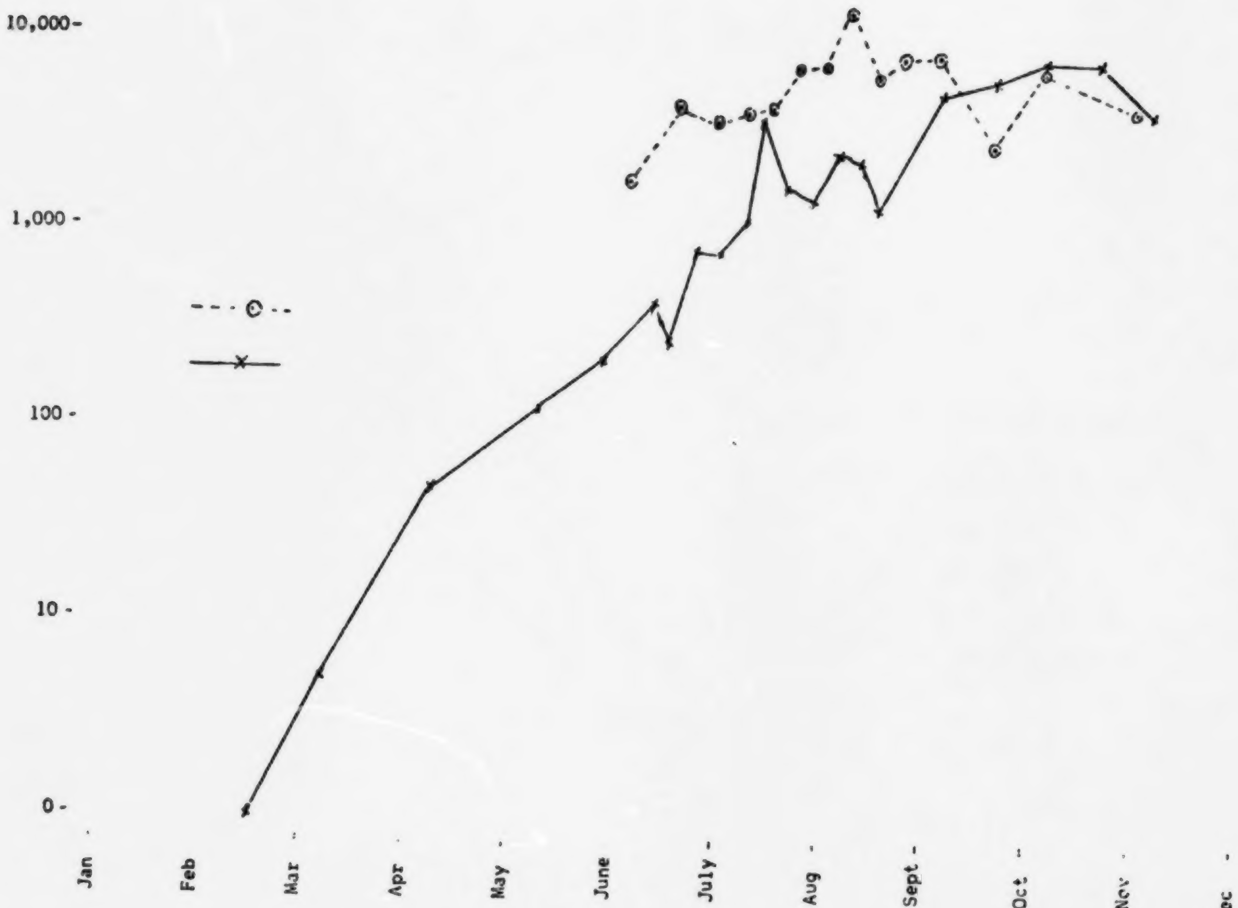

Exhibit 196. Total Phytoplankton Population Densities in Lake Herman During 1968 and 1970 (A-9)

Exhibit 107. CHANGES IN pH FROM LAKE TO SILT DEPOSIT AREA (A-9)

Date	Dredge Bay of Lake	Dredge Pipe Effluent	Silt Deposit Area	Deposit Area Outlet
7/28/70	9.07	--	8.26	--
8/11/70	9.12	8.08	7.69	7.20
8/18/70	9.19	7.30	7.80	--
8/26/70	--	7.6	7.28	7.27
9/3/70	9.32	8.39	8.35	7.98
9/22/70	9.16	8.50	8.44	8.28
10/6/70	9.07	8.34	--	8.16
10/13/70	8.93	8.27	8.53	7.89
10/21/70	8.97	8.32	--	8.14
11/3/70	8.85	--	7.98	7.97
7/13/71	9.19	8.06	--	--
8/18/71	8.98	8.13	8.55	--
8/25/71	9.13	8.49	8.57	7.83
9/13/71	8.80	8.15	7.95	--

Exhibit 198. CHANGES IN ORTHOPHOSPATE FROM LAKE TO SILT DEPOSIT AREA (A-9)

mg PO_4/l

Date	Dredge Bay of Lake	Dredge Pipe Effluent	Silt Deposit Area	Deposit Area Outlet
7/28/70	0.88	--	0.45	--
8/11/70	1.14	0.72	0.88	0.80
8/18/70	1.16	0.72	0.85	--
8/26/70	--	0.72	0.90	0.62
9/3/70	1.48	1.08	0.60	0.35
9/22/70	1.52	0.40	0.34	0.38
10/6/70	1.66	0.32	--	0.51
10/13/70	1.61	0.88	00	0.29
10/21/70	1.72	0.38	--	0.27
11/3/70	1.72	--	0.19	0.17
7/13/71	1.47	0.29	--	--
8/18/71	1.29	0.19	0.45	--
8/25/71	1.59	0.35	0.48	0.57
9/13/71	1.25	0.54	0.30	--

phosphorus levels. As dredging proceeded, the lower layers with less phosphorus were dumped in the disposal area, causing the phosphate levels to decrease still further.

The primary results of this study indicate that although dredging caused a large increase in phosphate levels, this change had no discernible ill effects on the biological components of this ecosystem.

Case 31. Study of Engineering Characteristics of Polluted Dredging

Source -

Krizek, R. J., Karadi, Gabor M. and Nammel, P. L., Engineering Characteristics of Polluted Dredging, Northwestern University Department of Civil Engineering, Evanston, Illinois. Prepared for the U.S. Environmental Protection Agency, March 1973.(A-33)

Purpose -

To examine the various physical, chemical, biological and engineering properties of the polluted maintenance dredgings taken from dredge hoppers, discharge pipes, fill areas, overflow weirs, and adjoining waters of several harbors along the Great Lakes. The results of the tests were to be used (a) to determine the pollution potential of the dredged materials, (b) to estimate the variations of the different water quality parameters measured for different locations; (c) to understand the engineering properties of the landfills and disposal sites, and (d) to identify the proper additive to improve the suitability of dredgings as building construction material or landfill material which may easily be used for wildlife refugees or recreational parks. The main idea of this overall investigation was to alleviate the environmental degradation caused by unsightly, unhealthy, and useless dredge disposal sites, and to transform the worthless dredging wastes into useful landfill materials.

Period of Study -

From October to July 1971.

Study Sites -

(a) Sampling sites were the following seven cities along the Great Lake.

1. Chicago, Illinois
2. Cleveland, Ohio
3. Detroit, Michigan
4. Green Bay, Wisconsin
5. Monroe, Michigan
6. Milwaukee, Wisconsin
7. Toledo, Ohio

The specific locations at which the samples were taken are shown in a series of detailed maps. (See Exhibit 199 as an example.)

(b) Testing was done primarily at Northwestern University. Some supplementary tests were conducted at the University of Wisconsin at Milwaukee and in the field at Toledo, Ohio. Some laboratory tests were performed by the EPA laboratory in Chicago.

Sampling Techniques and Scope of Tests/Study -
In order to get representative dredging samples, selective samples were taken at several different stages of dredging activities, e.g., before and during dredging operations, and during and after disposal operations. Generally, sampling was accomplished by use of an Ekman dredge or flap valve sediment sampler. The testing procedures used were generally those given in the Thirteenth Edition (1971) of Standard Methods for the Examination of Water and Waste Water,* but due to high concentrations of interfering compounds in some tests, small modifications were made.

Parameters Measured -

1. Northwestern University performed tests on 75 samples for the following parameters:
   (a) Metals: aluminum, arsenic, cadmium, calcium, copper, soluble and total iron, lead, mercury, potassium, and sodium.
   (b) Inorganics: ammonia nitrogen, nitrite-nitrogen, nitrate nitrogen, soluble and total phosphate, sulfide, and cyanide.
   (c) Organics: Organic nitrogen, hydrocarbon, oil and grease, and phenols.
   (d) Biological: chemical oxygen demand, biological oxygen demand, and dissolved oxygen.
   (e) Other: hydrogen ion concentration (pH), oxidation - reduction potential, turbidity, acidity, volatile solids, suspended solids and total solids.

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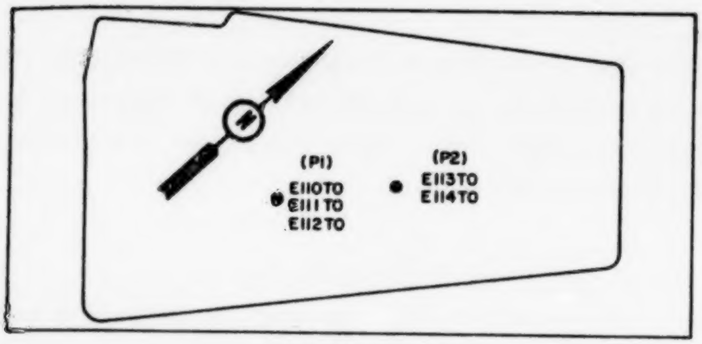
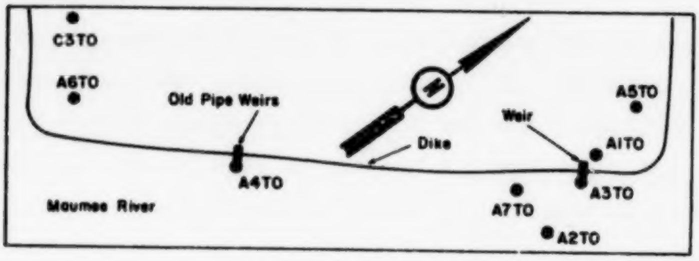
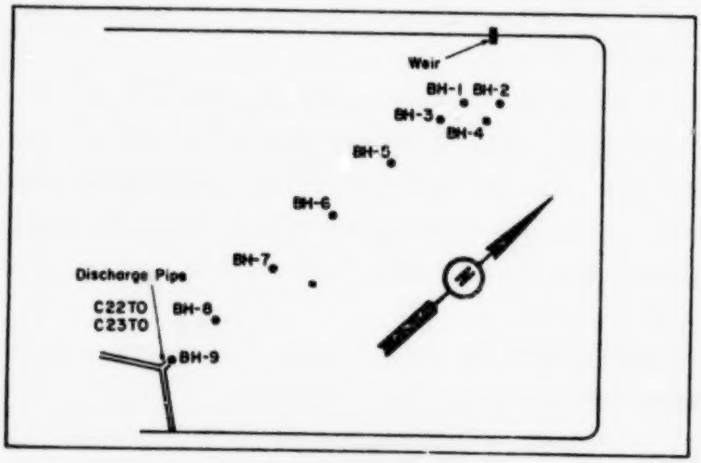
*Published by American Public Health Association, Washington, D.C.


(P1)
E110TO
E111TO
E112TO
(P2)
E113TO
E114TO

Penn 7 Disposal Area


C3TO
A6TO
Old Pipe Weirs
A4TO
Maumee River
Dike
Weir
A5TO
A1TO
A3TO
A7TO
A2TO

Penn 8 Disposal Area


Weir
BH-1
BH-2
BH-3
BH-4
BH-5
BH-6
BH-7
Discharge Pipe
C22TO
C23TO
BH-8
BH-9

Island Disposal Area

Exhibit 199. Example of Detailed Maps Showing Location of Sampling Sites(A-33)

2. University of Wisconsin at Milwaukee tested thirteen samples for:
   (a) clay minerology
   (b) cation exchange capacity
   (c) relative concentration of ions (seven)
   (d) calcium carbonate - calcite and dolomite
   (e) hydrogen ion concentration (pH)
   (f) organic carbon

3. Field Tests at Toledo - Ohio
   (a) For Surface: pH, turbidity, nitrogen, total alkalinity, phosphate, total hardness and iron.
   (b) Bottom Sediment: hydrogen sulfide, odor

4. EPA Laboratory: Pesticide tests of bottom sediments

Results -

Space limitations preclude inclusion of all quantitative results of interest that are contained in the referenced source document (about 330 pages). Examples of the analytical results obtained by the various testing organizations that participated in the study are reproduced in a series of exhibits in order that the reader may be aware of their nature and to aid him in deciding whether to go to the source document for additional detail.

- Examples of results from Northwestern University tests appear in Exhibit 200 ,
- Example of University of Wisconsin at Milwaukee test results appears in Exhibit 201 .
- Example of EPA Chicago Laboratory test results appears in Exhibit 202.
- Example of a special Field Task at Toledo, Ohio appears in Exhibit 203.

Exhibit 200 . EXAMPLE OF RESULTS OF CHEMICAL ANALYSES PERFORMED BY NORTHWESTERN UNIVERSITY

Sample	Total Solids	Total Volatile Solids	Total Suspended Solids	Total Volatile Suspended Solids	Turbidity	Acidity	Hydrogen Ion Concentration (pH)	Oxidation-Reduction Potential (Eh)	Dissolved Oxygen (DO)	Biological Oxygen Demand (BOD)	Chemical Oxygen Demand (COD)	Organic Nitrogen (N)	Ammonia (NH_3) Nitrogen (N)	Nitrite (NO_2) Nitrogen (N)	Nitrate (NO_3) Nitrogen (N)	Total Phosphate (PO_4)	Soluble Phosphate (PO_4)
	%	%	%	%	JTU	mg/gm		mv	mg/gm	mg/gm	mg/gm	mg/gm	mg/gm	mg/gm	mg/gm	mg/gm	mg/gm
A6	0.0670	34.26	3.03	0	0.65	326	7.6		13.6	7.1			0.06	1.23	26.67	2.02	0.39
A8	0.0909	9.40	0.36	0	1.10	125	7.3		0.2	10.7			10.78	2.02	33.12	3.30	0.10
A9	0.0507	20.98	0.44	0	0.79	129	7.2		14.3	24.0			0.07	1.27	7.50	10.50	1.03
A10	0.0974	10.80	3.36	1.50	4.3	209	7.6		8.3		17.5	3.66	0.40	0	0.02	2.36	0.99
A11	0.0353	23.06	3.56	2.55	3.6	413	7.5		28.0		36.8	6.79	0.68	0.06	0.36	2.61	1.67
A12	0.0164	21.21	10.57	5.06	4.0	621	7.9		86.4		0	5.22	0	0.03	0	4.52	2.70
A13	0.0437	37.07	9.40	1.23	10.0	273	7.6		30.3		79.1	3.56		0.90	5.93	3.12	1.00
A14	0.0450	30.09	5.11	1.04	19.0	300	7.0		24.9			3.36		0.70	8.29	1.78	1.07
A15	0.0519	15.99	7.64	2.15	22.0	318	7.7				66.3					4.65	
A16	0.0452	35.32	4.75	1.62	15.0	341	7.6		31.0		53.0	3.92	0.70	1.22	10.07	3.11	1.19
A17	0.0431	39.44	3.36	0.81	13.0		7.6				29.7		0.97			4.52	1.10
A18	0.0438	34.25	0.96	1.37	20.0	311	7.0		28.1		45.5	3.71	0.09	0.06	6.92	3.42	0.01
A19	0.0433	32.22	14.09	3.28	27.0	307	9.3		25.0		0.9	2.86	1.96	1.32	0	3.46	2.26
A20	0.0430	28.96	17.03	3.61	34.0	311	10.2		30.5		1.2	3.03	0	1.32	0	2.16	3.22
A21	0.0462	30.74	9.03	4.23	26.0	336	9.0		20.1		0.7	3.90	0	1.49	0	3.33	2.86
A22	0.0390	28.60	6.42	2.10	19.0	336	9.0		27.7		0.3	3.42	0	1.42	0	3.36	2.95

Sample	Grease	Hydrocarbons	Aluminum (Al)	Arsenic (As)	Calcium (Ca)	Copper, (Cu)	Total Iron (Fe)	Soluble Iron (Fe)	Potassium (K)	Silica (SiO_2)	Sodium (Na)	Sulfide (S)	Cadmium (Cd)	Cyanide (CN)	Lead (Pb)	Mercury (Hg)	Phenolics
	mg/gm	mg/gm	mg/gm	mg/gm	mg/gm	mg/gm	mg/gm	mg/gm	mg/gm	mg/gm	mg/gm	mg/gm	µg/gm	µg/gm	µg/gm	µg/gm	µg/gm
A6			0	0	144	0	0.40		25.0		53.2		0		655	0.002	
A8			0	0	73	0	.9		11.0		40.7		0		383	0.001	
A9			0	0	129	0	0.85		30.0		120.6		0		909	0.008	
A10			0		11	26.77	4.07	0.03	7.2		11.5		0		0	0.013	0
A11			0		29	106.73	3.20	0.07	7.6		58.6		0		0	0.013	0
A12			0		70	312.96	15.30	0	11.4		36.7		0		0	0.013	0
A13			0		230	3.70	8.09	0	12.5	0	41.7		0	0	0	0.001	3.7
A14			0		236	2.09	8.66	0	11.8	0	40.0		0	0	0	0.002	2.7
A15			0		263	2.11	8.12	0	14.6	0	52.5		0		0	0.001	
A16			0		274	3.23	17.41	0	14.2	0	56.7		0	0	0	0.001	4.0
A17			0		232	3.02	17.17	0	10.7	0	51.0		0		0	0.001	
A18			0		242	1.00	11.07	0	11.2	0	65.7		0	0	0	0.002	5.7
A19			11.55		370	0.55	12.01	1.16	11.1	0	76.2		0		0	0	0
A20			7.55		417	0.52	8.82	1.19	10.7	0	48.9		0	0	0	0.003	0
A21			0		448	0.82	3.73	1.26	11.7	0	57.3		0		0	0.002	67.2
A22			0		411	0.90	3.36	1.28	12.1	0	57.0		0		0	0.011	0

Exhibit 201. EXAMPLE OF RESULTS OF CHEMICAL AND MINERALOGICAL ANALYSIS OF SEVERAL DREDGINGS, PERFORMED BY UNIVERSITY OF WISCONSIN AT MILWAUKEE(A-33)

Sample	Clay Mineral (%)			Carbonates (%)	Calcite (%)	Dolomite (%)	Hydrogen Ion Concentration (pH)	Organic Carbon (%)	Cation Exchange Capacity (meq per 100 grams of dry material)	Ions (meq relative to milliequivalent of Calcium)						
	Illite	Kaolinite	Mixed Layer							Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Iron (Fe)	Sodium (Na)	Potassium (K)	Manganese (Mn)
C1DM	70	30	Trace	31.8	22.2	9.6	8.2	9.5	13.6	6.7	1	0.36	0.043	0.230	0.052	Trace
C2DM	60	20	20	29.3	19.0	10.3	7.6	8.8	15.1	3.3	1	0.31	0.008	0.170	0.030	Trace
C3TO	50	15	35	35.6	19.7	15.9	7.4	3.6	18.2	1.7	1	0.17	---	0.060	0.018	Trace
C4TO	50	15	35	36.4	21.8	14.6	7.2	3.7	15.3	2.8	1	0.21	---	0.120	0.033	Trace
C5CO	60	20	20	38.6	--	--	8.0	10.5	15.3	2.8	1	0.21	---	0.050	0.030	Trace
C7MW	--	--	--	39.9	9.9	30.0	6.4	15.1	21.9	3.6	1	0.23	---	0.035	0.019	Trace
C8MW	--	--	--	--	--	--	6.6	--	--	---	-	--	---	---	---	---
C9MW	--	--	--	38.4	9.6	28.8	7.1	7.7	14.8	4.4	1	0.21	---	0.035	0.023	Trace
C27MM	--	--	--	--	--	--	---	8.8	14.4	---	-	--	---	---	---	---
D1DM	65	35	Trace	24.6	--	--	7.2	10.1	14.0	3.7	1	0.15	---	0.060	0.033	Trace
D2DM	60	15	25	27.0	12.2	14.8	7.1	7.9	11.7	2.2	1	0.23	---	0.035	0.013	Trace
D3TO	50	15	35	28.1	16.9	11.2	6.9	5.1	15.8	1.4	1	0.32	---	0.050	0.023	Trace
D4CO	75	25	Trace	39.9	--	--	7.8	8.8	11.9	2.6	1	0.19	---	0.070	0.028	Trace

Exhibit 202. EXAMPLE OF RESULTS OF PESTICIDE ANALYSES OF BOTTOM SEDIMENTS PERFORMED BY EPA LABORATORY IN CHICAGO$^{(A-33)}$

Pesticide (ng/kg or ppt)	EPA Sample Number			
	8211	8212	8213	8214
	Northwestern University Sample Number			
	C2DM	C3TO	C5TO	D4CO
Lindane	35,309	33,194	1,819	24,272
Heptachlor	70,955	9,563	24,818	45,048
Aldrin	44,876	32,566	28,959	74,584
Heptachlor Epoxide	98,645	43,335	82,463	148,831
Methoxychlor	<1	<1	<1	<1
Dieldrin	<1	<1	<1	<1
Endrin	16,365	<1	33,862	18,071
o, p-DDE	120,563	47,379	114,583	185,355
P, p'-DDE	110,053	43,127	97,424	196,931
o, p-DDD	68,148	20,964	111,111	111,760
P, p'-DDT	89,293	34,305	145,653	110,637
o, p-DDT	121,637	15,558	32,669	24,417

Note: No separation of pesticides, PCB's, or phthalates was made; therefore, these values may include the above.

Exhibit 203. EXAMPLE OF RESULTS OF CHEMICAL CHARACTERIZATION OF FIELD SAMPLES AT TOLEDO (A-33)

	Parameter	Station[6]					
		55	50	20N	30N	30S	40
		Sample					
		A13	A14	A15	A16	A17	A18
Surface Water	Hydrogen Ion Concentration (pH)	7.40	7.40	7.40	7.50	7.50	7.60
	Turbidity (JTU)	20.00	20.00	25.00	15.00	15.00	23.00
	Nitrogen[1] (ppm)	35.40	38.10	32.80	35.40	34.60	35.40
	Total Alkalinity[2] (ppm)	140.00	138.00	135.00	135.00	135.00	135.00
	Phosphate[3]	0.75	0.72	0.72	0.75	0.85	0.85
	Total Hardness[4]	240.00	235.00	220.00	230.00	210.00	230.00
	Iron	0.05	---	0.05	---	---	0.05
Bottom Sediment	Hydrogen Sulfide	0.45	0.45	0.10	0.35	0.35	0.55
	Odor[5]	Strong	Strong & foul	Nil	Not so strong	Not so strong	Strong & foul

1. Nitrate and nitrite reported as nitrate.
2. Reported as CaCO$_3$, all in the form of bicarbonate alkalinity.
3. Ortho plus poly (meta) phosphate.
4. Reported as CaCO$_3$, EDTA method.
5. Oils and grease were visible on the surface of the sediment samples; all odors can be best described as "sewage" odors, which are typical of anaerobic activity.

The results of the above-cited analyses, when compared with suggested EPA guidelines for limiting concentrations of bottom sediments (See Exhibit 10), clearly show that the dredgings tested here are polluted though the extent of pollution varies from harbor to harbor and from sample to sample within one harbor. In some cases, the intensity of one or two parameters makes the dredgings highly polluted. The results also reveal that the dredgings are highly rich in plant nutrients, and when used as landfills, they will result in rapid growth of dense vegetation which will serve as food and shelter for animals in those areas or as flora for recreational parks. But before initiation of such actions, other processes which might involve possible pollution of groundwater, reservoirs and the subsequent effects of man must be considered.

Case 32. Hydraulic Dredging and the Effect of a Method of Spoil Disposal on Water Quality and Juvenile Salmon Survival in Port Gardner, Everett, Washington.

Source -

G. S. Jeane, II, and R. E. Pine, Hydraulic Dredging and the Effect of a Method of Spoil Disposal on Water Quality and Juvenile Salmon Survival in Port Gardner, Everett, Washington, Washington State University Department of Ecology, February 1973.(A-30)

Project Description-

To determine the effects of a dredging project in Everett Harbor, Washington, on the water quality of the harbor and bay, and to provide background data for the development of guidelines for dredging and dredge spoil disposal.

Project Description -

Approximately 66,300 m^3 of sediment were pumped into a two-cell settling basin by a cutter suction dredge. The project was designed to expand the cargo handling and ship docking capacity at the Hewitt Avenue terminal in the Port of Everett. Settling basins were constructed on both sides of Pier 3 (Exhibit 204). These basins were filled with the sediments dredged from the berthing areas adjacent to the pier. The berths were dredged to 7.6 m on the north and 12.8 m on the south side of the pier. The fill areas were built up to 6 m above MLLW (mean lower low water). In addition, an old pier was removed.

The dredged sediment fell into two classes: coarse sand and a fine-grained sludge-like material consisting of organic material and industrial wastes. The dredge had a pumping capability of 94.6 m^3/min of water containing 15 to 18 percent solids. The settling basins were equipped with an effluent weir.

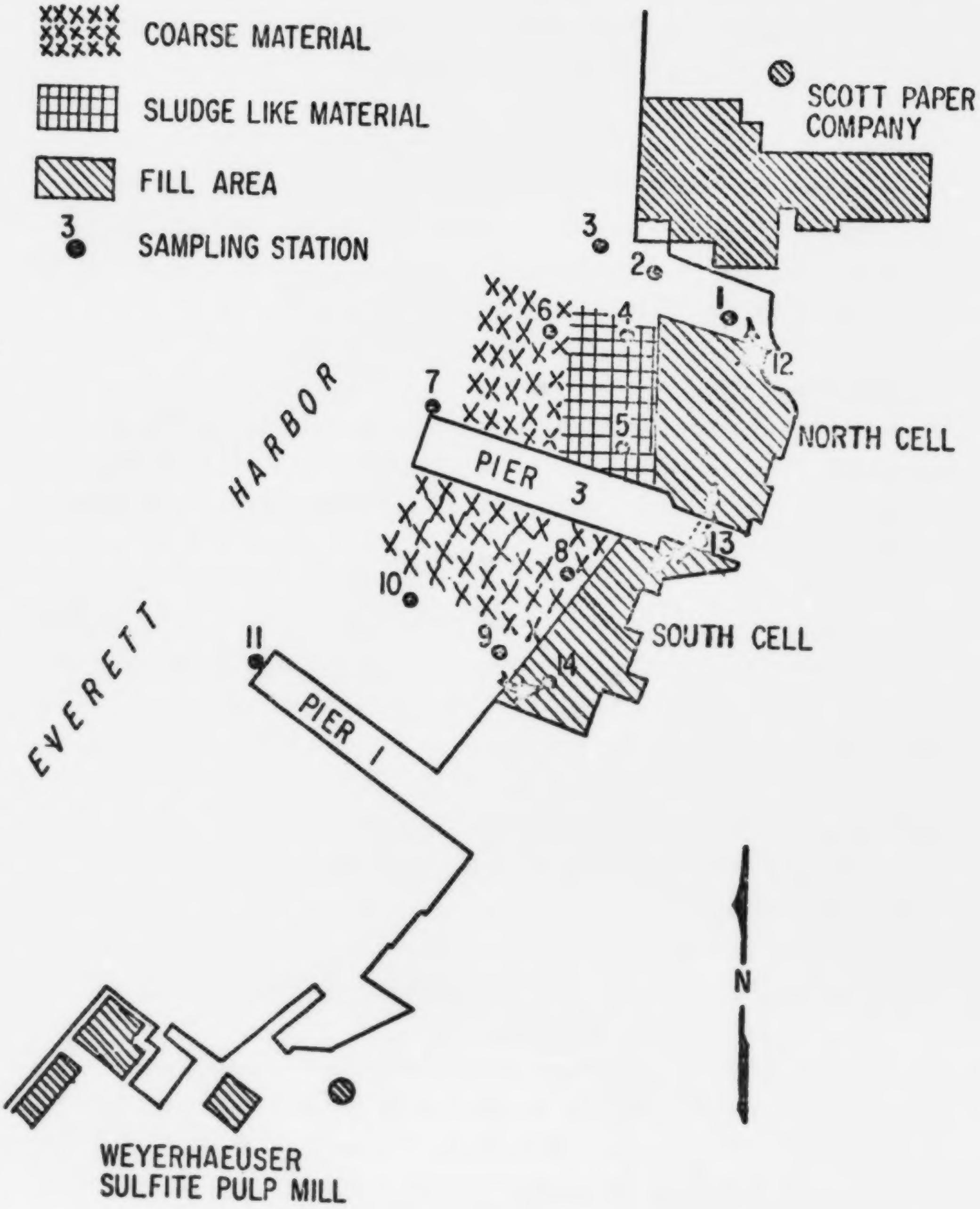

COARSE MATERIAL
SLUDGE LIKE MATERIAL
FILL AREA
SAMPLING STATION
SCOTT PAPER COMPANY
EVERETT HARBOR
PIER 3
PIER 1
NORTH CELL
SOUTH CELL
1
2
3
4
5
6
7
8
9
10
11
12
13
14
N
WEYERHAEUSER SULFITE PULP MILL

Exhibit 204. Location of Stations and Sediment Types (A-30)

Study Method -

Water quality and mortality rates of juvenile chinook salmon were determined both before and during dredging. The two sediment types were dredged separately. Fourteen stations were used, distributed to provide information on the dilution of the settling basin effluent (1, 2, 3, 4, 6); the efficiency of the basin (12, 13, 14); and the local effects of the dredging activity (station locations are shown in Exhibit 204). Samples were taken at 0.5 and 4.0 m depth. Five fish were kept at each station in live boxes made from 18-inch pieces of 12-inch fiberglass pipe.

Parameters Measured -

- Conductivity
- Salinity
- Temperature
- pH
- Dissolved oxygen
- Pearl Benson Index (PBI)
- Turbidity
- Sulfides
- Settleable solids
- Volatile solids
- Mercury
- Secci transparency

Results -

Water quality in the harbor before dredging is indicated in Exhibit 205. Water quality data observed during dredging of coarse materials and sludge are shown in Exhibits 206 and 207, respectively, salmon mortality data are given in Exhibit 208, and water quality data for the settling basins are presented in Exhibit 209.

Dissolved oxygen levels fell to approximately 60% of the predredge levels during the dredging of the sand, and to about 50% of the predredge level during the removal of the muds. PBI values decreased during coarse material dredging, but were up to twice the predredge values during the removal of the sludge-like material. Turbidity was excessive only in the immediate dredge area and near the settling basin outlet. Mercury values were 0.2 to 0.3 ppb during

Exhibit 205. WATER QUALITY DATA OBSERVED PRIOR TO DREDGING (A-30)

STA	DEPTH METERS	DISSOLVED OXYGEN mg/l	PBI mg/l	TURB JTU	SECCHI DISK METERS	VOLATILE SOLIDS (%)	Hg ppb	TOTAL SULFIDES mg/l
1	0.5	7.4	18	1	1.2	13	3.0	N.D.
		7.3	90	1	1.4	13		N.D.
		6.1	118	1	1.4	10		N.D.
		6.4	90	2	1.5	15		
		6.3	104	1	1.3	15		N.D.
			240	1	1.3	15	4.9	
2	0.5		63	1	1.5	12	1.4	
		6.9	95	1	1.8	14		N.D.
		6.9	95	1	1.5	17	1.6	N.D.
3	0.5		113	1	1.4		3.5	N.D.
		6.9	86	1	1.4	20		
		6.8	45	1	1.5	13		N.D.
			203	1	1.8	12	2.7	N.D.
4	0.5			1	1.5	14	2.1	N.D.
		6.4		2	1.4	16		N.D.
					1.5		2.1	
5	0.5		72		1.5		3.0	
		6.3	63	1	1.5	16		N.D.
		6.8	90	2	1.4	11	2.3	N.D.
				2	1.5	11		
6	0.5		68	1	1.5	13		
		6.3	59	1	1.5	16	4.3	N.D.
	–	6.5	99	1	1.5	17	5.1	N.D.
			68	1	1.5	16		
7	0.5		68	1	1.8			
		8.7	41	1	1.6	16	5.4	N.D.
		7.7	36	1	2.3	19	2.9	N.D.
					1.7	16		
8	0.5		41		1.8			
		8.1	41		1.8	11	4.5	N.D.
		7.1	90		1.2	13	2.9	N.D.
					1.7	13		
10	0.5		63	3		17		
		8.2	27	1	1.2	18	2.6	N.D.
		7.5	81	2	1.3	17	3.0	N.D.
					1.8			
11	0.5				1.8			
		7.1	59	1	2.1	19	2.4	N.D.
			72		2.1		3.5	

N.D. = None Detected

Exhibit 206. WATER QUALITY DATA OBSERVED DURING DREDGING OF COARSE MATERIAL (A-30)

STA	DEPTH METERS	DISSOLVED OXYGEN mg/l	PBI mg/l	TURB JTU	SECCHI DISK METERS	VOLATILE SOLIDS (%)	Hg ppb	TOTAL SULFIDES mg/l
1	0.5	4.8	9	1	1.5	13.5	0.14	N.D.
		5.0	14	3	0.9	15.0	0.80	
	4	4.2	14	3		13.5		
		4.7	18	4		15.7		
2	0.5	5.1	18	3	1.5	14.1	0.25	N.D.
		5.6	14	2	1.5	12.6		
	4	4.7	9	2		15.0		
		4.7	23	3		12.5		
3	0.5	5.5	14	1	1.5	13.2		
	4	4.1	41	2		11.9		
4	0.5	5.4	14	1	1.8	13.5	0.21	N.D.
	4	4.0	14	2		11.5		
5	0.5	5.7	14	1	2.1	11.8	0.33	N.D.
		4.5	18	2	1.4	11.3		
	4	4.3	14	2		11.8		
		3.7	23	3		11.7		
6	0.5	5.5	9		1.8	11.8	0.21	N.D.
		4.6	18	1	1.8	10.8		
	4	4.1	14	2		13.1		
		3.9	18	2		11.2		
7	0.5	5.8	14	2	1.8	11.8	0.11	N.D.
		5.6	23	2	2.1	16.3		
	4	4.2	18	1		12.6		
		5.0	18	2		11.7		
9	0.5	6.1	9	1	2.0	13.6	0.21	
		4.5	27	2	1.4	12.4		
	4	4.0	14	1		11.4		
		3.4	23	3		13.2		
10	0.5	6.0	18	2	2.4		0.33	N.D.
		5.0	23	2	1.5			
	4	4.2	14	2		16.2		
		3.8	18	1		10.4		
11	0.5	5.6	23	2	1.8	10.4		
	4	4.3	23	1		10.7		

N.D. = None Detected

Exhibit 207. WATER QUALITY DATA OBSERVED DURING DREDGING OF SLUDGE MATERIAL (A-30)

STA	DEPTH METERS	DISSOLVED OXYGEN mg/l	PBI mg/l	TURB JTU	SECCHI DISK METERS	VOLATILE SOLIDS (%)	Hg ppb	TOTAL SULFIDES mg/l
1	0.5	3.0	360	25	0.9	15.3		N.D.
		3.2	325	30		16.0		
	4	3.1	330	26				N.D.
		3.6	115	6		15.4		
2	0.5	3.1	465	15	0.3	15.9	0.11	
		4.0	85	4	1.1	18.2		
	4	3.6	370	15		52.5		
		3.4	75	1		18.2		
3	0.5	2.6	610	2	1.1	25.9		
		4.5	70	1	1.5	18.7	0.25	
	4	4.1	500	2		36.4		
			105	5		19.1		
4	0.5	3.0	500	3	0.9	39.3		
		3.9	90	1	1.5	18.6	0.08	
	4	3.2	340	6		51.7		
		3.4	70	5		19.9		
5	0.5	3.6	435	3	1.2	45.8		
		4.7	75	1	1.5	19.9	0.11	
	4	3.2	315	6		49.6		
		2.9	80	8		16.9		
6	0.5	2.9	565	3	1.1	31.9		
		3.7	85	1	1.5	17.5	0.10	
	4	3.4	465	5		89.6		
		2.6	60	15		19.2		
7	0.5	3.5	435	1	1.1	60.8		
		4.8	70	0	1.5	21.7	0.11	
	4	3.4	330	3		39.1		
		4.0	100	2		23.1		
10	0.5	3.5	320	1	1.5	57.8		
		5.1	70	1	2.0	10.9	0.11	
	4	2.9	295	3		18.1		
		3.5	60	1		11.6		
11	0.5	4.0	345	1	2.1	17.7		
		3.7	65	1	2.1	11.3	0.08	
	4	3.6	60	2		16.5		
		4.0	45	1		5.5		

N.D. = None Detected

Exhibit 208. PER CENT MORTALITY OF IN SITU BIOASSAYS FOR 24 HOURS EXPOSURE (UNLESS OTHERWISE NOTED)(A-30)

STATION	PREDREDGE	COARSE MATERIAL	SLUDGE MATERIAL
1	0	0 (5 hours)	0
2	0 (7 hours)	60%	20
3	0 (7 hours)	100	0
4	0	0	0
5	0	0	0
6	0	20	0 (5 hours)
7	0	20	20
8	0	0 (4 hours)	
9		0	
10	0 (7 hours)	0	0
11	0	0 (4 hours)	0

Exhibit 209. SETTLING BASIN WATER QUALITY PARAMETERS(A-30)

STATION	TOTAL SULFIDES mg/1	SETTLEABLE SOLIDS ml	VOLATILE SOLIDS (%)	TURB JTU	PBI mg/1	Hg ppb
		COARSE MATERIAL STUDY				
12	N.D.	Trace	10.9	50	9	0.21
	N.D.	Trace	10.8	26	9	0.29
						0.17
13	N.D.	37	11.1	40	5	0.27
	N.D.	25	11.9	35	9	0.25
14	4.0	150	11.0	750	9	0.17
	1.5	Trace	9.0	750	5	0.21
		SLUDGE MATERIAL STUDY				
12	N.D.	2.5	18	180	23	0.21
	N.D.	0.5		70	41	
13	0.5	250		2000	570	
	N.D.	200		2000	41	
14	8.0	50		2000	23	0.11
	N.D.	125		1000	5	

N.D. = None Detected

dredging, compared with 2 to 5 ppb prior to dredging. Sulfides ranged to 8 mg/l at the spoil landing, but were nil at the outlet weir. Salmon mortalities were not significant in the dredging and outfall areas, although some stress was noted in the salmon located near the spoil discharge. The only high mortality rate was observed at station 3 which was not near either the dredging area or the outflow, but happened to be near the outfall of a nearby paper mill.

The referenced report shows the results of a well-prepared dredging and spoil disposal program that did not significantly affect the surrounding bay, even during the actual removal of material.

Case 33. Demonstration of the Separation and Disposal of Concentrated Sediments, Prince George's County, Maryland.

Source -

Hittman Associates, Inc., Demonstration of the Separation and Disposal of Concentrated Sediments, Prince George's County, Maryland, HIT-570, Prepared for U. S. Environmental Protection Agency, Columbia, Maryland, February 1974.(A-25)

Purpose -

This project was designed to demonstrate: 1) a technique for small maintenance dredging operations which would have minimal adverse effects on the surrounding water body; and 2) a sediment processing system requiring a relatively small area, capable of removing most of the solids and returning clean water to the pond.

Site Description -

The pond chosen for this project was a small pond at the Bowie Airpark Site in Prince George's County, Maryland. Its characteristics are presented in Exhibit 210. Two years after it was built, it was 99 percent filled with sediment. The spillway elevations were raised in order to acquire the necessary depth (21 inches) to operate the dredge.

Sediment characteristics were determined from cores of the undisturbed sediment deposits. Sediment sizes are shown in Exhibit 211. Approximately 80 percent were between 10 and 100 microns in diameter. The initial water quality was determined from water samples taken two months before the dredging operations. Results appear in Exhibit 212.

Project Description -

The dredging operations consisted of two main components - the dredge itself and the processing and treatment equipment. The dredge used in this study was a Mud Cat, designed for use on small lakes

Exhibit 210. DEMONSTRATION POND CHARACTERISTICS (BOWIE, MARYLAND)(A-25)

Surface Area	1.7 acres
Maximum Depth	9.0 feet
Present Condition	99 percent filled with sediment
Age	2 years
Estimated Capacity	14,000 cubic yards

Exhibit 211. PHYSICAL CHARACTERISTICS OF COMPOSITE SEDIMENT IN POND BEFORE DREDGING

Grain Diameter (microns)	Percent Finer
250	99
150	95
100	91
40	12
8	7
3	6
1	2
Average Specific Gravity = 2.3	
In-Place Moisture Content = 28.8 to 50.3 percent	

Exhibit 212. POND WATER QUALITY BEFORE DREDGING OPERATIONS

Constituent	Concentration (mg/l unless stated otherwise) Location[a] 1	2	3	4	5
Sulphate	10	-	23	50	28
Phosphate	0.9	-	0.7	1.4	0.2
Iron	0.45	-	0.3	0.7	0.25
Copper	0.35	-	0.3	0.5	0.15
Zinc	0.00	-	0.01	3.25	0.00
NH_3	0.8	-	0.7	1.6	0.4
COD	-	-	3.4	7.6	1.6
Total Nitrogen	12.0	-	9.0	13.0	14.0
Coliform (Presumptive)	-	Positive 5/5	-	-	-
pH	6.0	-	6.75	6.1	6.1
Suspended Solids	-	-	381	745	37
Volatile Solids	531	-	67	68	42
Total Dissolved Solids	-	-	57	21	48
Total Solids	2980	-	505	834	137
Turbidity (JTU)	-	-	130	135	13
Oxidation-Reduction Potential (mv)	50	-	60	75	20

---

[a] Location Description:

1 - Pond inflow from watershed
2,3 - Near the inflow end of the pond
4 - Near the discharge end of the pond
5 - Pond discharge

to impart minimum turbidity to the water during its operation. Its capacity is approximately 2000 gallons per minute with a slurry solids concentration of 10 to 30 percent. Its maximum operating depth is 10.5 feet.

The processing system was composed of a pair of elevated settling bins, a bank of hydrocyclones, a standard cartridge-type water filter unit, and a bag-type filter. This filter is composed of a number of large-diameter hanging hoses through which the dirty water is pumped. The clean water filters through the hose and the sludge is periodically flushed. The system also incorporates a local temporary holding basin and a sludge disposal area. Exhibit 213 is a flow chart for the processing operations, including a mass balance.

Study Method -

During the dredging operation, water samples were taken from directly behind the dredge. These samples were analyzed to determine the amount of sediment resuspension due to the dredging activity. In addition, samples were taken from undisturbed water and compared with samples from the dredged slurry. Additional samples were taken after various phases of processing.

Parameters Measured -

- Sulfate
- Phosphate
- Iron
- Copper
- Zinc
- Redox Potential
- NH_3
- COD
- Total Nitrogen
- Coliform
- pH
- Concentrations of resuspended solids at various distances from dredge
- Suspended Solids
- Volatile Solids
- Total Dissolved Solids
- Total Solids
- Turbidity

Additional parameters were also measured for certain samples.

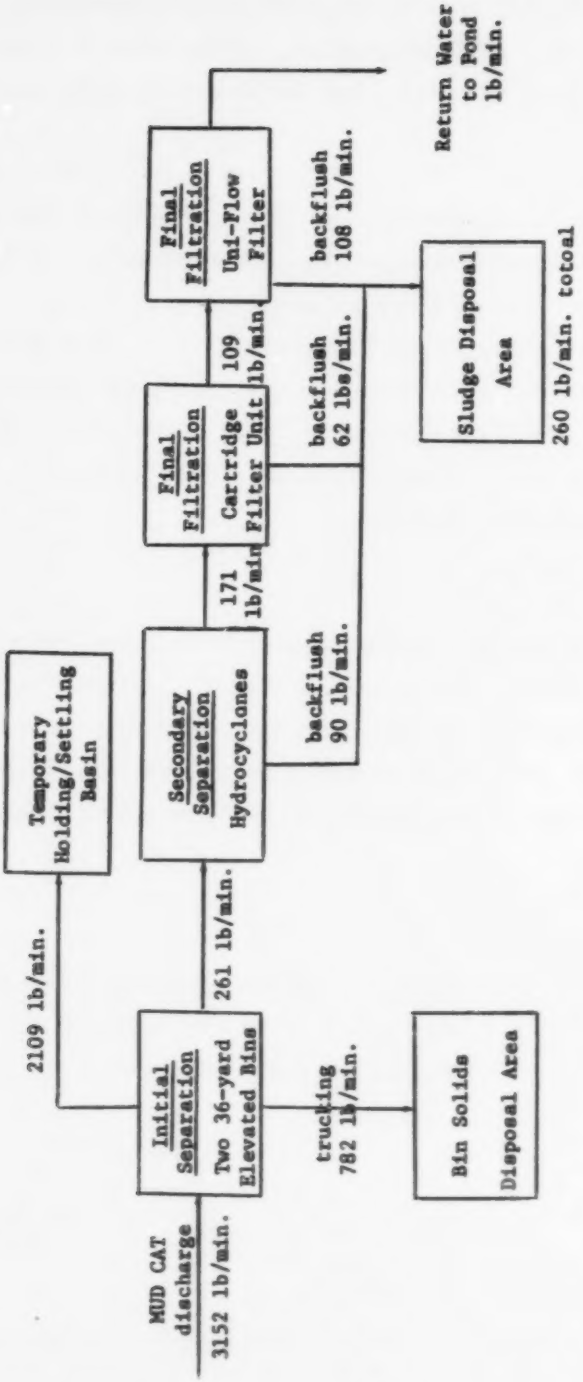

MUD CAT discharge
3152 lb/min.
Initial Separation
Two 36-yard Elevated Bins
2109 lb/min.
Temporary Holding/Settling Basin
261 lb/min.
trucking
782 lb/min.
Bin Solids
Disposal Area
Secondary Separation
Hydrocyclones
backflush
90 lb/min.
171 lb/min
Final Filtration
Cartridge Filter Unit
backflush
62 lbs/min.
109 lb/min
Final Filtration
Uni-Flow Filter
backflush
108 lb/min.
Sludge Disposal Area
260 lb/min. totoal
Return Water to Pond lb/min.

Exhibit 213. Flow Chart and Solids Balance for Processing System

Results -

During this study, 10,000 cubic yards of sediment was dredged from the pond. Exhibit 214 lists the fractions (of the total volume of sediment removed from the pond) that were removed by the various processing operations.

Exhibit 215 compares the chemical data for the dredged sediment and the lake water. Exhibit 216 gives the resuspension data. Exhibit 217 gives the results for the water quality after passing through various stages of treatment.

Average sediment concentration coming from the dredge was 170,300 mg/l. Average output from the processing system was 445 mg/l. Resuspension was low, its effects limited to within 20 feet of the dredge. The maximum concentration measured within the plume was 1,260 mg/l.

Altogether, this study describes an effective dredging program that can be used to extend the life of sediment-clogged ponds without adverse effects to the water quality.

Exhibit 214. DESTINATION OF DREDGED SEDIMENT

Destination	Quantity (cu.yd.)
Settled in Bins	750
Processed Through Remainder of System	250
Total Removed by System	1,000
Bins Overflow to Holding Basin	2,000
Total Pumped to Head End of System	3,000
Pumped to Conventional Settling Basin	7,000
Total Removed from Pond	10,000

Exhibit 215. ANALYSES OF COMPOSITE POND WATER SAMPLE AND DREDGED SLURRY SAMPLES

Constituent	Concentration (ppm unless stated otherwise)	
	Pond Water	Dredged Slurry
Zinc, as Zn	0.0	0.0
Chlorinated Hydrocarbons	0.000	0.000
Oil and Grease	24	7.5
Total Organic Carbon	12	68
Mercury, as Hg	0.0	0.0
Lead, as Pb	0.0	0.0
Oxidation-Reduction Potential	-4 mv	+14 mv
Total Dissolved Solids, @ 105° C.	148	77
Phenolphthalein Alkalinity, as $CaCO_3$	0	0
Total Alkalinity, as $CaCO_3$	36	15
Carbonate Alkalinity, as $CaCO_3$	0	0
Bicarbonate Alkalinity, as $CaCO_3$	36	15
Carbonates, as CO_3	0	0
Bicarbonates, as HCO_3	43.9	18.3
Hydroxides, as OH	0	0
Carbon Dioxide, as CO_2	6	200
Chloride,as Cl	42	30
Sulfate, as SO_4	52	39
Fluoride, as F	0.0	0.0
Phosphate, as PO_4	0.3	0.55
pH (Laboratory)	7.1	5.1
pHs	8.8	9.3
Stability Index	10.5	13.5
Saturation Index	-1.7	-4.2
Total Hardness, as $CaCO_3$	39	15
Calcium Hardness, as $CaCO_3$	18	12
Magnesium Hardness, as $CaCO_3$	21	3
Calcium, as Ca	7.2	4.8
Magnesium, as Mg	5.1	0.7
Sodium, as Na	9.6	8.1
Iron, as Fe	5.6	9
Manganese, as Mn	0	3.7
Copper, as Cu	0.02	0.0
Silica, as SiO_2	6	11
Color, Standard Platinum Cobalt Scale	65	80
Odor Threshold	0	6
Turbidity, Jackson Units	20	100+

Exhibit 216. RESUSPENSION OF POND SEDIMENTS

(a) RESUSPENSION OF POND SEDIMENTS DURING DREDGING
7/5/73

Operating Condition	Distance from Front of Dredge (ft.)	Depth below Surface (ft.)	Suspended Solids Concen. (mg/l)
Before Dredging	5	1	39
	5	3	50
	5	5	64
	5	7(bottom)	523
Dredging (forward cut)	5	1	88
	5	5	179
	5	7(bottom)	1260
	10	1	54
	10	5	86
	20	1	39

(b) RESUSPENSION OF POND SEDIMENTS DURING DREDGING - 7/6/73

Operating Condition	Distance from Front of Dredge (ft.)	Depth below Surface (ft.)	Suspended Solids Concen. (mg/l)
Before Dredging	5	Depth Integrated Composite - 0 ft. to bottom	89
Dredging (forward cut)	4	1	900
Dredging (forward cut)	10	1	649
	10	5	175
Dredging (forward cut)	20	1	226

Exhibit 216 (continued). RESUSPENSION OF POND SEDIMENTS

(c) RESUSPENSION OF POND SEDIMENTS DURING DREDGING - 7/11/73

Operating Condition	Distance from Dredge (ft.)	Depth below Surface (ft.)	Suspended Solids Concen. (mg/l)
Before Dredging	5 ft. from front	1	18
		4	75
		7 (bottom)	1000
Dredging (forward cut)	5 ft. from front	1	72
		7 (bottom)	1257
Dredging (forward cut)	5 ft. from side	1	89
Dredging (forward cut)	1 ft. behind	1	1262

(d) RESUSPENSION OF POND SEDIMENTS DURING DREDGING - 7/18/73

Operating Condition	Distance From Front of Dredge (ft.)	Depth below Surface	Suspended Solids Concen. (mg/l)
Before Dredging	5	1	34
Dredging (forward cut)	5	1	83
	10	1	19

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Exhibit 217. SUSPENDED SOLIDS CONCENTRATIONS IN PROCESSING SYSTEM

te	Suspended Solids at Sampling Point (mg/l) # 5	# 1	# 2	# 3	#4	Average System Flow (gpm)	Remarks
6/25/73	158,000		29,500	*	190	300	3 hr. composite samples; 2 Uni-Flow hoses with holes
				*	1440	300	sample after 1 Uni-Flow hose burst
6/26/73					150	250	2 hr. composite sample
					136	250	" " "
					340	250	" " "
7/2/73	261,000	231,700	149,500	105,400	240	300	4 hr. composite samples
7/11/73				*	47	250	2 hr. composite sample
				*	491	250	" " "
				*	1127	250	" " "
7/12/73	195,200	151,200	108,000	87,200	100	200	3 hr. composite sample
7/13/73		76,400	52,400	*	184	200	2 hr. composite sample; cartridge filters bypassed
	254,000	254,000	179,600	50,400	227	200	2 hr. composite sample; bins completely full of sediment
7/14/73					398	250	2 hr. composite sample; bins completely full of sediment
7/23/73	129,200	61,300	40,400	26,200	230	100	composite sample of run
7/26/73	107,600	87,600	31,400	22,700	570	100	Composite sample of run
7/27/73	107,000	67,400	44,700	26,200	660	300	Composite sample of run
7/30/73	138,000	55,800	49,500	34,700	520	250	Composite sample of run
8/1/73		140,500	103,800	94,400	1770	200	Composite sample of run
8/6/73			+	*		250	15 min. av. flow; Uni-Flow pressure = 8 psi
	158,200	135,900	+	*	208	120	15 min. av. flow; Uni-Flow pressure = 10 psi; 1/2 hr. composite samples
			+	*		70	15 min. av. flow; Uni-Flow pressure = 12 psi
	96,300	70,100	+	*	137	60	15 min. av. flow; Uni-Flow pressure = 12 psi; 1/2 hr. composite samples
			+	*		50	15 min. av. flow; Uni-Flow pressure = 10 psi
	145,900	84,500	+	*	424	30	15 min. av. flow; Uni-Flow pressure = 11 psi; 1/2 hr. composite samples

+ hydrocyclones bypassed
* cartridge filters bypassed

Sampling Point Key

# 5 = MUD CAT discharge into elevated bins
# 1 = Bin effluent - influent to hydrocyclones
# 2 = Hydrocyclone effluent - influent to cartridge filters
# 3 = Cartridge filter effluent - influent to Uni-Flow filters
# 4 = Uni-Flow effluent (return water to pond)

Case 34. Characterization of Pollutant Availability for San Francisco Bay Dredge Sediments

Source -

Pacific Northwest Laboratories, Battelle Memorial Institute, Characterization of Pollutant Availability for San Francisco Bay Dredge Sediments. Prepared for U. S. Army Engineer District, San Francisco, California. Richland, Washington, January 1974.(A-38)

Purpose -

This report describes a crystalline matrix study of sediments dredged from San Francisco Bay. It is the first phase of a larger study to "determine the quantity and nature of certain heavy metals and polychlorinated biphenyls (PCB's) that are released from selected San Francisco Bay sediments." The case study was selected for inclusion in the present report because it reveals the types of pollutants likely to be released by dredging in industrialized bay areas.

Site Description-

Ten sampling stations were picked from the shipping channels located throughout the estuary. They were selected to represent the range of sediment types and pollution concentrations commonly involved in maintenance dredging. They are shown in Exhibit 218. The sampling was done between August 14 and August 17, 1973.

Sediment Characteristics -

Physical, chemical and mineralogical characterization was performed for sediments from each sampling station. Total acid soluble sulfide concentrations varied from 4 to 2000 ppm. Most samples were about 60% clay with 10% sand, while Outer Harbor Channel samples contained 50% or more sand. The cation exchange capacities of the sediments ranged between 10 and 35 millequivalents per 100 grams of dry sediment. The clay mineral montmorillonite was the chief source of this exchange

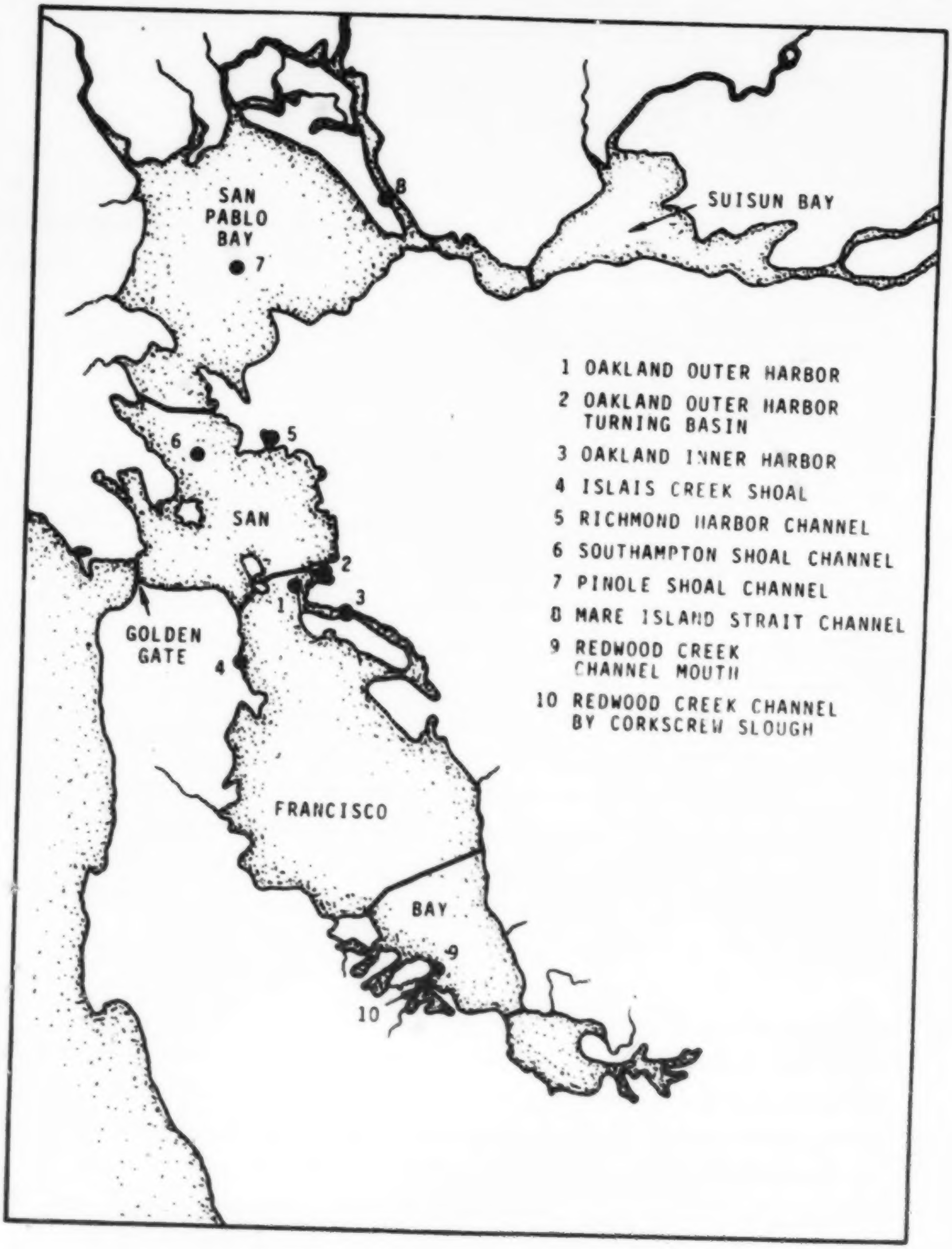
SAN PABLO BAY
SUISUN BAY
SAN
FRANCISCO
BAY
GOLDEN GATE
1
2
3
4
5
6
7
8
9
10
1 OAKLAND OUTER HARBOR
2 OAKLAND OUTER HARBOR TURNING BASIN
3 OAKLAND INNER HARBOR
4 ISLAIS CREEK SHOAL
5 RICHMOND HARBOR CHANNEL
6 SOUTHAMPTON SHOAL CHANNEL
7 PINOLE SHOAL CHANNEL
8 MARE ISLAND STRAIT CHANNEL
9 REDWOOD CREEK CHANNEL MOUTH
10 REDWOOD CREEK CHANNEL BY CORKSCREW SLOUGH

Exhibit 218. Location of Sampling Stations

capacity. Average organic carbon was 1.4 percent. Carbonate concentrations ranged from 0.2 to 1.0 percent. PCB concentration varied from 0.03 ppm to 0.9 ppm. Lead and mercury concentrations varied in the range 10 ppm to 110 ppm for lead and 0.05 ppm to 1.1 ppm for mercury. Copper varied from 80 to 190 ppm and zinc from 90 to 270 ppm both slightly higher than the accepted levels cited in most of the literature; cadmium ranged from 0.5 to 1.6 ppm, although the data is subject to verification. Addition detailed data from these unusually complete characterizations of bottom sediments appear in Exhibits 219 through 226.

It was determined that in general, copper and lead are difficult to extract and that cadmium is the easiest of the metals studied to remove by chemical extraction. The cadmium in the samples used for the extraction studies was concentrated on ion exchange sites. Much of the copper, lead and mercury appeared to be bound in mineral lattice positions and with hydrous oxides and iron oxides. Acid conditions were generally needed in order to remove significant amounts of these metals from the sediment.

The referenced report provides abundant information on the sediments most likely to be dredged from the channels of the San Francisco Bay. It will be helpful in the determination of potential pollution during dredging and disposal operations.

Exhibit 219. DESCRIPTION OF SEDIMENT FROM VARIOUS STATIONS

SAMPLE		ICED SAMPLES SOIL/SOLUTION	WET	DEBRIS/ODOR	DRY
Oakland Outer Harbor (Seventh Street)	#1-V	High solids	Black mud/some sand	None	Brownish powder, faint traces of quartz sand
	#2-H	High solids	Black mud/some sand	None	Brownish powder, no visible sand
Oakland Outer Harbor Turning Basin	#1-V	Medium solids	Black mud	Large clam shell	Brownish powder
	#2-V	Low solids	Black mud		Brownish powder
Oakland Inner Harbor	#1-V	High solids	Black mud		Brownish powder
	#2-V	High solids	Black mud, oily layer	Large shell, piece wood	
Islais Creek Shoal	#1-V	Medium solids	Rich black		Brownish powder
	#2-V	Medium solids	Black, sticky layer		Brownish powder
Richmond Harbor Channel	#1-V	High solids	Black	Clam shell, looked alive; oil smell	Brownish powder
	#2-V	Low solids	Rich black		Brownish powder
Southampton Shoal Channel	#1-H	High solids	All sand	Broken bits of shell	Brown sand, shell fragments
	#2-V	High solids	All sand	One small clam shell, many broken bits	Brown sand, shell fragments
Pinole Shoal Channel	#1-V	Low solids			Brownish powder
	#2-V	Low solids			Brownish powder (very little sample)
Mare Island Straits Channel	#1-V	Medium solids	Black mud		Brownish powder
	#2-V	Medium solids			Brownish powder
Redwood Creek Channel at mouth	#1-V	3/4 Empty			Brownish powder
	#2-V (Al)	Medium solids		Sewage odor	Brownish powder
Redwood Creek by Corkscrew Slough	#1-V	Medium solids	Black mud, some brownish sand	A small shell	Brownish powder

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*Refers to material of which collection apparatus was constructed. See Footnotes on Exhibit 204.

Exhibit 220. TOTAL ACID SOLUBLE SULFIDE AND H_2S CONCENTRATIONS

LOCATION	MOORING	SEDIMENT DESCRIPTION	SAMPLES TAKEN		REMARKS
			ALUMINUM	PVC	
Oakland Outer Harbor (Seventh Street)	Buoy "3" Fl 4 sec 8	Top few inches mud, hard underlayer	#1 Vertical #2 Horizontal	#1 Vertical #2 Horizontal	#2 Samples contained more water than #1 samples
Oakland Outer Harbor Turning Basin	Northern dock by U. S. Army cranes, across from first crane	Black mud for more than 2 ft depth	#1 Vertical #2 Vertical	#1 Vertical #2 Vertical	High solids content
Oakland Inner Harbor	Southern dock at Alameda Army supply dock	Black soft mud for more than 2 ft depth	#1 Vertical #2 Vertical	#1 Vertical #2 Vertical #3 Vertical #4 Vertical	#2 Samples taken 100 ft further east from #1 sample location; much debris on bottom
Islais Creek Shoal	Docked on south side about one-third of the way in	Black soft mud for more than 2 ft depth	#1 Vertical #2 Vertical	#1 Vertical #2 Vertical	No debris evident
Richmond Harbor Channel	Docked on east side at Terminal # 3	Black soft mud for more than 2 ft depth	#1 Vertical #2 Vertical	#1 Vertical #2 Vertical	Debris evident; sediments smelled oily; #2 taken 100 ft north
Southampton Shoal Channel	Tied off Buoy "ISS" on S.E. corner of channel	Brownish sand	#1 Vertical #2 Vertical	#1 Horizontal #2 Vertical #3 Vertical #4 Lost	#1 Aluminum only half full; #4 PVC lost when boat moved, pulling diver away from sampling tube
Pinole Shoal Channel	Tied off northern black can, Buoy # 5	Top 5.5 inches--brownish sand/mud; 4 inches--black mud to bottom--gray mud	#1 Vertical #2 Vertical	#1 Vertical #2 Vertical	Looked for sand with grab sampler but could not find
Mare Island Strait Channel	Moored off west cable crossing	Black mud	#1 Vertical #2 Vertical	#1 Vertical #2 Vertical	Strong current; brown colored water; water at other locations colored green
Redwood Creek Channel at the mouth	Moored off Buoy "5", 130 ft S.W. into channel	Black mud	#1 Vertical #2 Vertical #3 Vertical	#1 Vertical	Samples contain much water; #1 PVC--most lost in transit
Redwood Creek Channel by Corkscrew Slough	Moored off buoy marked "15" on Chart 5531	Black mud	#1 Vertical	#1 Vertical #2 Vertical #3 Vertical	Samples contain much water; lost end cap on #3 PVC

Page 1 of 2

Exhibit 220(continued). TOTAL ACID SOLUBLE SULFIDE AND H_2S CONCENTRATIONS

SAMPLE	TYPE*	TOTAL SULFIDE** (ppm)	H_2S INTERSTITIAL WATER (ppm)
Mare Island Strait Channel	PVC 1 V	185	
	PVC 2 V	1000	
	AL 1 V	365***	.034
Redwood Creek Channel at the mouth	PVC 1 V	1020	
	AL 3 V	1150	
	AL 1 V	952	.016
Redwood Creek by Corkscrew Slough	PVC 1 V	570	
	AL 1 V	1210***	.016

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*Samples taken in PVC or aluminum (AL) pipe in a vertical (V) or horizontal (H) position.

**Dry weight basis.

***Dewatered frozen core samples stored in contact with air for a period of 3.5 weeks. Results may be low by a factor of 2.

Exhibit 221. PARTICLE SIZE DISTRIBUTION

SAMPLE	TYPE*	PARTICLE SIZE** (Hydrometer)	PARTICLE SIZE** (Hope-Kittrick)
Oakland Outer Harbor (Seventh Street)	PVC 1 V	50-22-28	44-33-23
	PVC 2 H	31-30-39	60-24-16
	AL 1 V	59-17-24	
Oakland Outer Harbor Turning Basin	PVC 1 V	2-28-70	1-47-52
	PVC 2 V	6-25-69	1-51-48
	AL 1 V	3-28-69	
Oakland Inner Harbor	PVC 1 V	16-26-58	12-45-43
	PVC 2 V	31-21-48	
Islais Creek Shoal	PVC 1 V	6-34-60	1-52-47
	PVC 2 V	7-33-60	
	AL 1 V		
Richmond Harbor Channel	PVC 1 V	6-32-62	1-53-46
	PVC 2 V	9-33-58	
Southampton Shoal Channel	PVC 1 H	91-5-4	92-6-2
	PVC 2 V	91-3-7	
	AL 2 V		
Pinole Shoal Channel	PVC 1 V	12-38-49	9-58-33
	PVC 2 V	9-33-58	
Mare Island Strait Channel	PVC 1 V	6-43-51	3-58-39
	PVC 2 V	9-38-53	4-54-42
	AL 1 V	8-41-51	
Redwood Creek Channel at the mouth	PVC 1 V	8-35-57	1-57-42
	AL 3 V	5-37-58	2-45-53
	AL 1 V	6-35-59	
Redwood Creek by Corkscrew Slough	PVC 1 V	12-31-56	9-52-39

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*Samples taken in PVC or aluminum (AL) pipe in a vertical (V) or horizontal (H) position.

**Values represent percent sand, percent silt, and percent clay, rounded to the nearest percent respectively.

Exhibit 222. PARTICLE SIZE DISTRIBUTION OF SEDIMENT-CLAY FRACTION AND QUALITATIVE RESULTS FOR MONTMORILLONITE CLAY

	Percent of Total for Each Size Fraction					% Total Sample With Montmorillonite Detected	
Sample Location	<.2μ	.2--2μ	2-5μ	5--20μ	20-75μ		CEC*
Oakland Outer Harbor	8.5M**	14.4M	6.3	9.3	17.3	23.9	15.9
Oakland Outer Harbor Turning Basin	24.7M	28.1M	16.3M	21.4	9.4	69.1	35.2
Oakland Inner Harbor	16.4M	26.2	14.6	17.5	13.2	16.4	26.2
Islais Creek Shoal Channel	22.1M	25.1	14.2	19.4	19.2	22.1	33.1
Richmond Harbor Channel	23.3M	22.9M	13.9M	22.5	16.3	60.1	32.2
Southampton Shoal Channel	0.8M	1.2	1.6	2.0	2.4	0.8	10.3
Pinole Shoal Channel	12.2M	20.8M	13.4	24.5	21.0	33.0	31.1
Mare Island Straits Channel	18.1M	21.2M	13.1M	22.1M	22.5	75.5	28.1
Redwood Creek Channel at Mouth	14.0M	27.8M	12.8	19.7	24.8	41.8	30.3
Redwood Creek Channel at Corkscrew Slough	13.3M	25.7M	13.5	21.0	17.5	39.0	33.4

*CEC = Cation Exchange Capacity
**M denotes montmorillonite detected

Exhibit 223. CATION-EXCHANGE CAPACITY DATA

Sample Location	Sample Type	No. of Determinations	Sample Average (meq/100g)	Location Average (meq/100g)
	Clean Beach Sand	7	0.088	
Oakland Outer Harbor	AL 1	2	11.8	15.9
	PVC 1	2	15.2	
	PVC 2	2	20.7	
Oakland Outer Harbor Turning Basin	AL 1	2	37.5	35.2
	PVC 1	2	36.0	
	PVC 2	3	33.2	
Oakland Inner Harbor	AL 1	3	24.7	26.2
	PVC 1	2	28.6	
	PVC 2	2	26.0	
Islais Creek Shoal	AL 1	4	33.4	33.1
	PVC 1	2	33.4	
	PVC 2	2	32.0	
Richmond Harbor Channel	AL 1	3	33.7	30.6
	PVC 1	2	32.0	
	PVC 2	2	26.1	
Southampton Shoal Channel	AL 2	1	11.9	10.6
	PVC 1	2	9.5	
	PVC 2	2	10.4	
Pinole Shoal Channel	AL 1	3	34.1	31.1
	PVC 1	2	28.4	
	PVC 2	2	29.3	
Mare Island Shoal Channel	AL 1	2	29.5	28.1
	PVC 1	3	26.2	
	PVC 2	2	29.6	
Redwood Creek Channel at Mouth	AL 1	2	31.0	30.3
	PVC 1	3	29.3	
	PVC 2	2	31.2	
Redwood Creek Channel at Corkscrew Slough	PVC 1	2	33.4	33.4

Exhibit 224. ORGANIC CARBON AND CARBONATE DATA

	Sample Type*	Organic Carbon%	Organic Matter%**	% Ash	Carbonate Content% by Difference	Carbonate Content by Calcimeter%
Oakland Outer Harbor	PVC 1	1.10	1.98	83.7	0	0.25
	PVC 1	0.63	1.13	92.8	0.15	
	PVC 2	1.06	1.91	88.18	3.35	
Oakland Outer Harbor Turning Basin	AL 1	1.72	3.10	86.7	0.55	0.39
	PVC 1	1.63	2.93	95.9	1.90	
	PVC 2	1.58	2.84	82.6	0.45	
Oakland Inner Harbor	AL 1	1.16	2.09	92.0	0	0.63
	PVC 1	1.49	2.68	83.4	0.25	
	PVC 2	0.97	1.75	96.7	0.45	
Islais Creek Shoal	AL 1	-	-		-	0.42
	PVC 1	1.76	3.17	82.7	0.65	
	PVC 2	1.79	3.22	85.3	0.35	
Richmond Harbor Channel	AL 2	1.40	2.52	86.9	0.65	0.85
	PVC 1	1.56	2.81	88.8	0.30	
	PVC 2	1.48	2.66	84.8	1.10	
Southampton Shoal Channel	AL 1					0.09
	PVC 1	0.05	0.09	87.6	0.25	
	PVC 2	0.14	0.25	95.9	0.00	
Pinole Shoal Channel	AL 1					1.31
	PVC 1	1.17	2.11	85.7	0.25	
	PVC 2	1.08	1.94	79.6	0.40	
Mare Island Straits Channel	AL 1	1.56	2.81	88.3	1.55	0.42
	PVC 1	1.65	2.97	88.5	0.05	
	PVC 2	1.69	3.04	86.6	0.10	
Redwood Creek Channel at Mouth	AL 1	1.48	2.66	94.2	0.50	0.58
	PVC 1	1.34	2.41	86.4	0.65	
	PVC 2	1.33	2.39	76.6	0.15	
Redwood Creek Channel by Corkscrew Slough	PVC 1	1.33	2.39	82.2	5.55	3.30

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*Samples taken in PVC or aluminum (AL) pipe in a vertical (V) or horizontal (H) position.

**Organic matter % = 1.8 x Organic C%

Exhibit 225. CONCENTRATION OF PCB's AND PESTICIDES IN SEDIMENT SAMPLES

Sample Location	Dry Weight Basis (ppm)				
	DDE	DDD	DDT	PCB	Dieldrin
Southampton Shoal Channel*	0.002	0.007	0.006	0.030	<0.001
Oakland Inner Harbor	0.041	0.091	0.118	0.833	0.001
Oakland Outer Harbor Turning Basin	0.011	0.029	0.037	0.239	0.002
Redwood Creek Channel at Mouth	0.007	0.014	0.021	0.137	0.006
Redwood Creek Channel at Corkscrew Slough	0.002	0.006	0.004	0.052	0.001
Oakland Outer Harbor	0.009	0.016	0.012	0.099	0.002
Mare Island Straits Channel	0.010	0.017	0.007	0.084	0.001
Richmond Harbor Channel*	0.024	0.083	0.065	0.189	0.005
Islais Creek Shoal	0.010	0.026	0.032	0.280	0.002
Pinole Shoal Channel	0.001	0.002	0.002	0.026	<0.001

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*Samples taken from AL 2 cores. All other samples were taken from AL 1 cores.

Exhibit 226. RESULTS OF SEDIMENT ANALYSIS FOR SELECTED HEAVY METALS BY X-RAY FLUORESCENCE, NEUTRON ACTIVATION, AND ATOMIC ABSORPTION

Sample	Type	Metal Concentrations, mg/kg Dry Weight								
		Pb		Cu		Cd	Hg		Zn	As
		XRF*	AA*	XRF	AA	AA	NAA*	AA	XRF	NAA
Oakland Outer Harbor	PVC 1V	30	27	106	--	0.66	0.3	0.26	105	6
	PVC 2H	38	---	111	--	----	1.6	0.47	150	8
Oakland Outer Harbor Turning Basin	PVC 1V	89	---	170	--	----	1.1	0.48	212	15
	PVC 2V	68	---	145	--	----	---	0.67	189	--
Oakland Inner Harbor	PVC 1V	102	130	170	121	1.25	2.5	1.02	214	13
	PVC 2V	118	---	207	--	----	---	1.13	230	--
Islais Creek Shoal	PVC 1V	85	70	165	77	1.60	3.2	0.62	218	13
	PVC 2V	95	---	164	--	----	---	0.64	247	--
Richmond Harbor Channel	PVC 1V	63	91	143	76	1.31	1.5	0.56	196	13
	PVC 2V	71	---	157	--	----	---	0.60	234	--
Southampton Shoal Channel	PVC 1H	13	---	56	--	----	<1	0.05	91	6
	PVC 2V	6	---	78	--	----	---	0.03	90	--
Pinole Shoal Channel	PVC 1V	12	---	126	--	----	1.1	0.32	140	10
	PVC 2V	38	---	136	--	----	---	----	161	--
Mare Island Strait Channel	PVC 1V	50	63	182	71	0.61	0.8	0.64	181	14
	PVC 2V	40	---	138	--	----	---	0.47	160	--
Redwood Creek Channel at the Mouth	PVC 1V	51	41	121	60	0.89	<1	0.56	174	9
	AL 3V	56	---	104	--	----	---	0.32	177	--
Redwood Creek Channel by Corkscrew Slough	PVC 1V	85	---	172	--	----	1.1	0.41	266	10

*XRF = x-ray fluorescence; AA = atomic absorption; and NAA = neutron activation analysis.

APPENDIX F: APPLICATION OF CONTROL MEASURES

General

This appendix presents summaries of eight case studies dealing with the observed effectiveness of various control measures as applied at construction sites. Quantitative information concerning the amounts of sediment generated by a given type of construction activity on a site with known pertinent parameters is available to the greatest extent for out-of-stream construction. This also holds true for observations of the effectiveness of control measures. Applicable physical, topographic, climatic and soil information are given when available, in addition to all information concerning the control measures and the effects of these measures.

Case 35. Controlling Soil Movement from Steep Roadfills, Boise, Idaho

Source -

Bethlahmy, N. and Kidd, W. J. Jr., Controlling Soil Movement from Steep Roadfills, Boise, Idaho. U. S. Forest Service Research Note INT-45, USDA, Inter-Mountain Forest and Range Experiment Station, 1966.(A-5)

Purpose -

To compare and evaluate different soil-stabilizing treatments on the fill slope of a newly constructed mountain road.

Site Location -

The study took place along the side of Bogus Basin Road, a two-lane highway between Boise and Bogus Basin ski resort. The highway is built through the steep terrain and erodible soils of the Boise National Forest. The soils are derived from weathering of the granitic Idaho batholith.

Project Description -

Eight adjacent test plots 43.6 feet in length and 10 feet wide were constructed along a raw fill slope with an average gradient of 80 percent. A sediment trough was placed at the bottom of each plot. One plot was left untreated, while the other seven were subjected to various combinations of seeding, mulching and netting. Cumulative records of precipitation and sediment loss were collected during the study period.

Time Frame-

This project began in the fall of 1962. Time zero was November. Six measurements were taken during the next 11 months, ending October 11, 1963.

Parameters Measured -

Cumulative time, cumulative precipitation, cumulative sediment due to erosion from each of eight plots (thousands of pounds per acre).

The Experiment -

The eight plots were treated as shown in Exhibit 227. They can be effectively divided into three groups: Group A containing (Plots 2 and 4) - seeding and fertilizer; Group B (Plots 3 and 8) - seeding, fertilizer and straw mulch; Group C (Plots 5, 6 and 7) - seeding, fertilizer, straw mulch and netting. Plots 2 and 3 were contour furrowed with a 6-foot spacing between the furrows. They were also punched with 2-inch holes at 6-inch intervals. The straw mulch was applied at a rate of 2 tons per acre. The polymer emulsion, "Soil Set," was diluted to one-tenth strength, with five gallons of the dilution applied before seeding and five gallons after 300 lbs. of asphalt emulsion per acre were applied to Plot 8. The netting was fastened with 12-inch staples of No. 9 wire.

Results -

Exhibit 228 shows that the combination of all three methods gives the best results. Plots 2 and 4, which were seeded only, showed more erosion than the control plot, which had no treatment at all. The averages for each group were: Group A - 97.1 x 10^3 lbs/acre; Group B - 24.0 x 10^3 lbs/acre; Group C - 0.5 x 10^3 lbs/acre.

No cost comparison was included in this paper, so an economic analysis cannot be made. It would, however, appear that Plot 3, which was treated by contour furrowing, mulching, and fertilizing might be a feasible solution if netting costs are high. This plot yielded only 11.9 x 10^3 lbs/acre over 11 months compared to 84.2 x 10^3 lbs/acre for the untreated plot. A more complete cost analysis is needed as an addition basis for choice of method in any given application.

Exhibit 227. CULTIVATION TREATMENTS

Plot number	Sequence of treatment
1	Control--no treatment at all.
2	Contour furrows, seed, fertilizer, holes.
3	Contour furrows, straw mulch, seed, fertilizer, holes.
4	Polymer emulsion, seed, fertilizer.
5	Straw mulch, paper netting, seed, fertilizer.
6	Straw mulch, jute netting, seed, fertilizer.
7	Seed, fertilizer, straw mulch, chicken wire netting.
8	Seed, fertilizer, straw mulch with asphalt emulsion.

Exhibit 228. COMPARISON OF CUMULATIVE EROSION FROM TREATED PLOTS ON A STEEP ROAD FILL

(in 1,000 lbs. per acre)

Cumulative elapsed time (days)	Cumulative precipitation	Control plot	Group A (seed, fertilizer)		Group B (seed, fertilizer, mulch)		Group C (seed, fertilizer, mulch, netting)		
			Plot number						
			2	4	3	8	5	6	7
	Inches								
17	1.41	31.9	38.7	38.0	0.1	32.6	0	0	0
80	4.71	70.0	99.2	85.7	7.4	34.6	0.9	0	0.3
157	12.46	72.2	100.2	86.9	11.1	35.1	1.1	0	0.4
200	15.25	79.1	101.0	87.6	11.4	35.7	1.1	0	0.4
255	17.02	82.3	102.8	88.8	11.5	35.8	1.1	0	0.4
322	20.40	84.2	104.7	89.4	11.9	36.0	1.1	0	0.4

Case 36. A Fertility Survey of Exposed Subsoils from Highway Road Banks in the Coosa Watershed of Northwest Georgia.

Source -

Hendrickson, B. H., "A Fertility Survey of Exposed Subsoils from Highway Road Banks in the Coosa Watershed of Northwest Georgia," Journal of Soil and Water Conservation, Vol. 13, No. 1, January 1958.(A-23)

Purpose -

This study was performed to gain knowledge that might be helpful in reestablishing vegetation on unprotected road bank cuts, which constitute a major silt source.

Site Location/Description -

The investigation took place at virgin roadbank cuts in the Coosa Watershed of Northwest Georgia. Laboratory tests were conducted at the University of Georgia in Athens.

Topography -

Road banks ranged in slope from 1:1 to 1:3. Height of slope was generally 10 to 20 feet, but some were as high as 30 or 40 feet. The banks had many gullies and were subject to large amounts of rapid runoff, with resulting high rates of soil removal.

Soil Types -

The seven soil series investigated in this study included Cecil, Lloyd, Helena, Madison, Louisa, Talladega, and Louisburg. All of these soils were developed from old igneous and metamorphic rock formations comprised of granite, granite-gneiss, schist, mica-schist, and hornblende gneiss. Six of these profiles are deeply weathered soils. Talladega is a shallow rick, A-C soil.

Study Methods -

Soil material from both B and C horizons of five soil types, Cecil, Lloyd, Helena, Madison, and Louisa, and from the C horizon of A-C profiles of the Talladega and Louisburg series were collected from road-bank cuts. The samples were transported to the laboratory where soil analyses were made on 12 lots and then the soil material was placed in 1-gallon pots. Six fertilization treatments were added to each sample. Uniform rates of 200 lbs/acre of N, 400 lbs/acre of P_2O_5 and 200 lbs/acre K_2O, 2 tons/acre of dolomitic limestone, and 100 lbs/acre of Esminel were applied in the following 6 combination treatments.

Serial No.	Combinations
1	NK only
2	PK only
3	NP only
4	NPK
5	NPK + lime
6	NPK + lime - Esminel

Southland Oats were planted and 6 successive forage clippings were made above the 3-inch height. Oven dried weights were recorded.

Results -

It was found that as a whole, these soils were acid in reaction and contained only a trace of available phosphorus. Potash content was variable but generally low. Nitrogen and phosphorus fertilization afforded strong responses and should be considered essential in the establishment of vegetation on subsoils. Results are given in Exhibits 229, 230, and 231.

Exhibit 229. AVERAGE OAT FORAGE YIELDS IN THE GREENHOUSE WITH SIX FERTILITY TREATMENTS

			Yields in grams per pot treated with					
	Soil Series	Horizons	NK	PK	NP	NPK	NPK + Lime	NPK + Lime + Esminel
I	Cecil	B	.32	1.29	3.81	4.25	7.72	8.40
		C	.09	3.05	3.15	3.73	6.98	6.24
II	Lloyd	B	.21	.57	5.90	6.49	7.04	8.76
		C	.21	1.36	6.60	3.62	6.19	7.91
III	Helena	B	.20	1.58	3.86	5.48	6.66	7.24
		C	.25	1.70	5.00	6.69	7.52	5.89
V	Madison	B	.17	1.10	2.39	4.11	6.72	5.34
		C	.19	.30	2.59	4.00	6.78	6.04
VI	Louisa	B	.09	.70	4.49	4.60	7.58	6.60
		C	.12	.51	2.35	2.58	6.28	5.31
IV	Talladega	C	.33	2.02	4.03	3.63	5.91	6.71
VII	Louisburg	C	.67	.77	3.02	5.27	4.85	5.09

Exhibit 230. SOIL ACIDITY LEVEL AS AFFECTED OF LIME TREATMENT OF TWO TONS PER ACRE

Soil and Horizon			Treatment without lime	with lime
			pH	pH
Cecil	B		4.8	6.1
	C		4.7	6.2
Lloyd	B		5.1	6.5
	C		5.1	6.4
Helena	B		5.1	6.3
	C		5.2	6.1
Madison	B		4.9	6.5
	C		4.9	6.6
Louisa	B		5.0	6.5
	C		4.9	6.6
Talladega	C		4.6	6.3
Louisburg	C		5.1	6.6
		Average	5.0	6.4

Exhibit 231. ORIGINAL POTASH LEVELS OF ALL SAMPLES, AND THE RESPONSE OF OATS TO POTASH FERTILIZATION IN THE GREENHOUSE TESTS

	B-Horizons					C-Horizons				
		Oat Forage Yields					Oat Forage Yields			
Soil Series	K_2O Content lbs/acre	in treatments NP grams	NPK grams	Differences grams	%	K_2O Content lbs/acre	in treatments NP grams	NPK grams	Differences grams	%
Madison	20	2.39*	4.11	+1.72	+72	36	2.59*	4.00	+1.41	+54
Helena	40	3.86	5.48	+1.62	+42	40	5.00	6.69	+1.69	+34
Cecil	60	3.81	4.25	+ .44	+12	52	3.15	3.73	+ .58	+18
Lloyd	92	5.90	6.49	+ .59	+10	64	6.60	3.62*	-2.98	-45
Louisa	148	4.49	4.60	+ .11	+ 2	80	2.35	2.85	+ .50	+21
Louisburg	—	—	—	—	—	36	3.02	5.27	+2.25	+75
Talladega	—	—	—	—	—	124	4.03	3.63*	- .40	-10

*A low-yielding erratic replicate is involved with each average. These data are regarded as unreliable.

Case 37. Erosion Control Study of Louisiana, Road Side Channels.

Source -

Cox, A. L. et al., "Erosion Control Study, Part II - Roadside Channels" Highway Research Report, U. S. Department of Transportation, Federal Highway Administration, April 1971.(A-10)

Purpose -

This study was performed by the Louisiana Department of Highways to develop erosion control measures for controlling erosion in the roadside drainage channels with varying soil conditions, slopes, lengths and runoff rates.

Site Location/Description -

The grass-lined channels which were involved were located on opposite sides of State Highway 67; two are about 8-1/2 miles north of Clinton, Louisiana, and two are about 8 miles south of the town. The bare, eroded channels were located on the opposite sides of State Highway 441, eight channels lie along the side of State Highway 32 in the area around Greensburg. One channel was located along U. S. 61 about 12 miles north of Baton Rouge.

Topography -

The bare channels differed slightly in slope, length and soil type. Slope percentages ranged from 1 to 5; the average was 3.9. Channel length varied from 450 to 850 feet and averaged 586.36 feet.

Soil Type -

Most of the sites were comprised of Providence Silty Clay Loam, although Lexington Silty Clay Loam was evidenced at two channels and Ruston Sandy Clay Loam was found at two others. Oliver Silty-Clay Loam was also found at one channel site.

Study Methods -

The study was done in two phases, the first covering field observations for four stable grass-lined channels and 11 severely eroded channels. This phase started in the winter of 1964-65 and lasted until the spring of 1966. During the second phase, eight of the observed channels were reworked and tested for various types of ditch liners.

Parameters Measured -

The main characteristics which are considered in this study are plasticity index, pH, channel slope percent, channel length in feet, observed peak discharge in c.f.s., and increase in cross sectional area of channel by erosion in square feet.

Results -

Roadside drainage channels with varying soil conditions slopes, lengths, and runoff rates were compared for their efficiency in handling erosion problems (see Exhibit 232). The results indicate that the channels with runoffs of five cfs or less are eroding soils up to one cubic foot per linear foot of channel per year, and those conveying larger flows are losing quantities of soil. This erosion is occuring in channels which have acid soils low in essential plant nutrients.

This study also points out that some kind of temporary channel liner is required for protection of newly seeded channels against erosion during critical periods between seeding and the establishment of protective growth. Protective growth can be rapidly developed by lining the channel with solid slab sod or with some approved temporary liners.

Exhibit 232. SUMMARY OF OBSERVATION CHANNEL CHARACTERISTICS*

	Soils						Observed	Increase in
					Channel	Channel	Peak	Cross sectional
					Slope	Length	Discharge	Area of Channel
Channel	Name	Type	P.I	pH	Percent	Feet	c. f. s.	by Erosion Sq. Ft.
441-1L	Lexington	Silty Clay Loam	14	4.8	5	450	5.0	1.2
441-1R	Lexington	Silty Clay Loam	12	4.8	5	450	4.3	1.4
37-1L	Providence	Silty Clay Loam	19	5.0	3	550	16.0	1.3
37-1R	Providence	Silty Clay Loam	20	5.1	3	550	6.0	0.8
37-2L	Providence	Silty Clay Loam	10	4.8	3	500	3.6	2.3
37-2R	Providence	Silty Clay Loam	9	4.7	3	500	3.6	2.1
37-3L	Providence	Silty Clay Loam	14	4.5	5	550	-	1.4
37-3R	Providence	Silty Clay Loam	16	4.6	5	550	-	1.2
37-4L	Ruston	Sandy Clay Loam	11	4.2	5	750	3.2	3.6
37-4R	Ruston	Sandy Clay Loam	14	4.3	5	750	3.2	2.8
61-1L	Oliver	Silty Clay Loam	10	5.0	1	850	40.0	6.0

* Observations conducted over 18-month period beginning in winter of 1964-65 and ending in the spring of 1966.

P. I. - Plasticity Index
pH - Soil Acidity

Case 38. Protecting Steep Erosion Slopes Against Water Erosion, Progress Report 2

Source-

U. S. Department of Agriculture, "Protecting Steep Construction Slopes Against Water Erosion," Progress Report 2, Soil and Water Conservation Research Division, Lincoln, Nebraska, September 1967.(A-52)

Purpose -

This study was conducted by the U. S. Department of Agriculture's Soil and Water Conservation Division to evaluate the effectiveness of different mulching materials in protecting the freshly shaped roadside cuts and embankments against erosion. Simulated rainstorm experiments were used for these experiments.

Site Location/Description -

The study site was located on the back slope of a dam on the V. Karsan farm, north and west of Wahoo, Nebraska, about 30 miles north of Lincoln.

Soil Type -

Twenty-two plots of Sharpsburg silty clay loam (sand 9%, silt 55%, clay 36%) at a slope of 2:1 made up the actual study area. Each plot was 10 feet x 20 feet.

Study Methods -

During the study period, which lasted through 1966 and 1967, 13 different mulching materials or combinations of materials were applied and measurements were made for losses of soil, grass seed, and phosphorus fertilizer which were contained in the run-off from the plots.

The simulated rainfall was produced by a tractor-mounted machine (rotator-type) which produced raindrops with energy close to that of natural raindrops. A sequence of four storms was used for the experiments to each pair of plots: 2.0 hours @ 2.5 inches per hour (iph); 1.0 hr. @ 2.5 iph; 0.3 hr. @ 5 iph; 0.8 hr. @ 2.5 iph.

Results -

Measurements were derived from 22 plots of land following simulated rainstorms of varying duration and intensity. Exhibit 233 represents the loss of phosphorous during three simulated rainstorms and Exhibit 234 gives the erosion rates for various mulch treatments which are graphed in Exhibit 235 . All treatments have been compared to jute net mulch as a check. Mulch materials are ranked according to their effectiveness in Exhibit 236.

All treatments resulted in high seed and fertilizer retention, although their movement within the plot was not determined. Eleven of the plots failed through "soil slides," the mass downslope movement of saturated mud. This generally occurred in the fourth storm, after the soil had absorbed the equivalent of several inches of water. The plots that did not fail were generally the plots that allowed greater runoff and therefore more erosion.

Incomplete results from the increased runoff studies indicate that glassroot anchored by asphalt provides the greatest protection at high runoff rates.

Exhibit 233. LOSS OF PHOSPHORUS IN THE SOIL REMOVED AND WATER RUNOFF FROM PLOTS WITH VARIOUS MULCH TREATMENTS FOR A SERIES OF THREE SIMULATED RAINSTORMS. HIGHWAY PROJECT, WAHOO, NEBRASKA, 1966.

Mulch treatment	Rep	Storm 1			Storm 2			Storm 3			Total for three storms
		Eroded soil	Water runoff	Total	Eroded soil	Water runoff	Total	Eroded soil	Water runoff	Total	
		pounds per acre									
Glassroot	1	.02	.04	.06	.00	.01	.01	.00	.01	.01	.08
	2	.07	.37	.45	.07	.16	.23	.12	.16	.29	.97
	Av.	.04	.20	.25	.03	.08	.12	.06	.08	.15	.52
Asphalt emulsion	1	.00	.01	.01	.00	.03	.03	.00	.00	.01	.05
	2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	Av.	.00	.00	.00	.00	.01	.01	.00	.00	.00	.02
Prairie hay and asphalt emulsion	1	.00	.00	.00	.00	.00	.00	.00	.02	.03	.03
	2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	Av.	.00	.00	.00	.00	.00	.00	.00	.01	.01	.01
Woodchips and asphalt emulsion	1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	2	.00	.00	.00	.00	.01	.01	.02	.08	.10	.11
	Av.	.00	.00	.00	.00	.00	.00	.01	.04	.05	.05
Corncobs and asphalt emulsion	1	.00	.00	.00	.00	.00	.00	.00	.02	.03	.03
	2	.01	.05	.06	.05	.03	.08	.15	.10	.25	.39
	Av.	.00	.02	.03	.02	.01	.04	.07	.06	.14	.21
Wood excelsior	1	.00	.00	.00	.01	.00	.02	.03	.03	.06	.08
	2	.09	.01	.11	.03	.00	.04	.03	.01	.05	.20
	Av.	.04	.00	.05	.02	.00	.03	.03	.02	.05	.13

Page 1 of 2 pages

Exhibit 233 (continued). LOSS OF PHOSPHORUS IN THE SOIL REMOVED AND WATER RUNOFF FROM PLOTS WITH VARIOUS MULCH TREATMENTS FOR A SERIES OF THREE SIMULATED RAINSTORMS. HIGHWAY PROJECT, WAHOO, NEBRASKA, 1966.

Mulch treatment	Rep	Storm 1			Storm 2			Storm 3			Total for 3 storms
		Eroded soil	Water runoff	Total	Eroded soil	Water runoff	Total	Eroded soil	Water runoff	Total	
		pounds per acre									
Soil Retention Matt	1	.00	.00	.00	.01	.03	.04	.04	.05	.10	.14
	2	.00	.00	.00	.00	.05	.05	.05	.07	.12	.17
	Av.	.00	.00	.00	.00	.02	.04	.04	.06	.11	.15
Excelsior and wood cellulose	1	.00	.00	.01	.01	.02	.03	.10	.04	.14	.18
	2	.02	.03	.05	.21	.16	.37	.52	.09	.62	1.04
	Av.	.01	.01	.03	.11	.09	.20	.31	.06	.38	.61
Jute-net	1	.00	.00	.00	.02	.00	.03	.01	.01	.02	.05
	2	.00	.00	.00	.00	.08	.09	.03	.06	.10	.19
	Av.	.00	.00	.00	.01	.04	.06	.02	.03	.06	.12
Conweb	1	.08	.04	.13	.06	.04	.11	.05	.04	.10	.34
	2	.00	.01	.02	.06	.05	.12	.06	.03	.09	.23
	Av.	.04	.02	.07	.06	.04	.12	.05	.03	.09	.28
Silva-fiber	1	.00	.00	.00	.01	.01	.03	.12	.05	.18	.21
	2	.00	.00	.00	.01	.02	.03	.07	.06	.13	.16
	Av.	.00	.00	.00	.01	.01	.03	.09	.05	.15	.18

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Exhibit 234. MULCH TREATMENTS RANKED ACCORDING TO RELATIVE EFFECTIVENESS FOR PROTECTION AGAINST WATER EROSION.

ALL TREATMENTS ARE COMPARED TO A JUTE-NET MULCH AS A CHECK.
HIGHWAY PROJECT, WAHOO, NEBRASKA, 1966

Mulch	Rate applied per acre	Relative erosion [1/] (Number of times the erosion from jute-net mulch)
Asphalt emulsion	1200 gal	0.16
Woodchips anchored with asphalt emulsion	6 tons with 150 gal	0.28
Jute-net		1.00 [2/] and [3/]
Prairie hay anchored with asphalt emulsion	1 ton with 150 gal	1.04
Soil Retention Matt		1.59
Corncobs anchored with asphalt emulsion	5 tons with 150 gal	2.34
Silva-fiber	1400 lb	3.10
Glassroot anchored with asphalt emulsion	1000 lb and 150 gal	3.45
Excelsior	2 ton	3.91
Conweb	1400 lb	8.11
Excelsior and cellulose	350 lb excelsior and 1050 lb cellulose	15.00

1/ Total erosion of three simulated rainstorms replicated twice for each mulch treatment

2/ Mulch treatment used for comparison purposes

3/ Average erosion rate for Jute net mulch = 0.33 tons/acre.

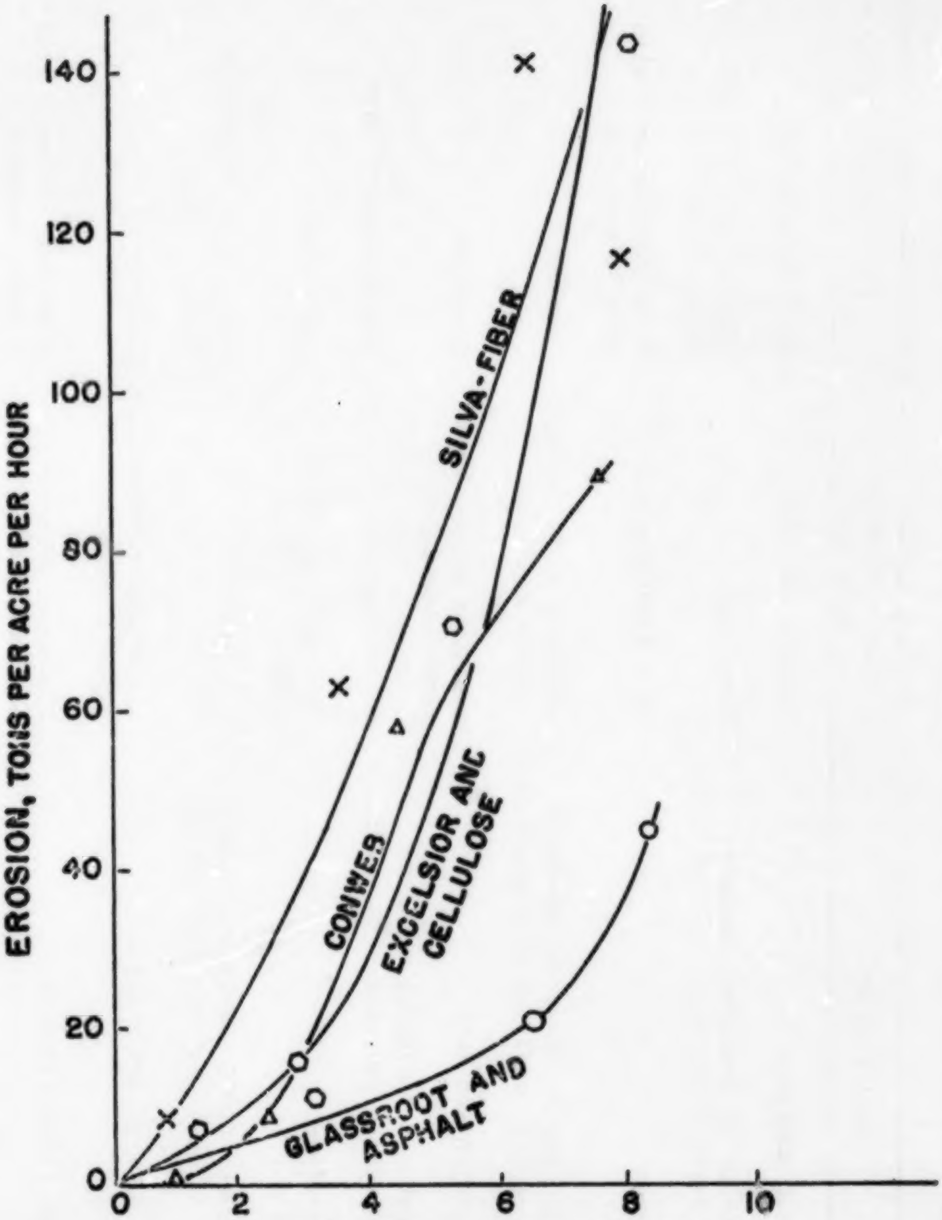


Exhibit 235. Rates of Erosion as Related to Various Rates of Runoff on Four Mulch Treatments, 2:1 Fill Slope, Wahoo, Nebraska, 1966

Exhibit 236. SUMMARY OF MULCH MATERIALS ARRANGED ACCORDING TO DESIRABLE TRAITS (LEAST EROSION AND LOSS OF SEED AND PHOSPHORUS). HIGHWAY PROJECT, WAHOO, NEBRASKA, 1966

	Soil erosion	Lincoln bromegrass seed loss	Total phosphorus loss
1	Asphalt emulsion	Asphalt emulsion	Asphalt emulsion
2	Woodchips (6 ton/acre) anchored with asphalt emulsion (150 gal/acre)	Excelsior	Prairie hay anchored with asphalt emulsion
3	Jute-net	Soil Retention Matt	Woodchips anchored with asphalt emulsion
4	Prairie hay (1 ton/acre) anchored with asphalt emulsion (150 gal/acre)	Corncobs anchored with asphalt emulsion	Jute-net
5	Soil Retention Matt	Corncobs anchored with asphalt emulsion	Excelsior
6	Corncobs (5 ton/acre) anchored with asphalt emulsion (150 gal/A)	Silva-fiber	Soil Retention Matt
7	Silva-fiber	Prairie hay anchored with asphalt emulsion	Silva-fiber
8	Glassroot (1000 lb/acre) anchored with asphalt emulsion (150 gal/A)	Jute-net	Corncobs anchored with asphalt emulsion
9	Excelsior (2 ton/acre)	Woodchips anchored with asphalt emulsion	Conweb
10	Conweb (1400 lb/acre)	Glassroot anchored with asphalt emulsion	Glassroot anchored with asphalt emulsion
11	Excelsior (350 lb/acre) and cellulose (1050 lb/acre)	Excelsior and cellulose	Excelsior and cellulose

Case 39. Study of Erosion Control on Highway Slopes in Georgia

Sources -

(a) Barnett, A. P. and et al., "Evaluation of Mulching Methods for Erosion Control on Newly Prepared and Seeded Highway Backslopes," Agronomy Journal, Vol. 59, 1967, 83-85.(A-3)

(b) Diseker, E. G., and E. C. Richardson, "Roadside Sediment Production and Control," Transactions of the ASAE, Vol. 4, 1961, 62-68.(A-15)

(c) Diseker, E. G., and E. C. Richardson, "Erosion Rates and Control Methods on Highway Cuts," Transactions of the ASAE, Vol. 5, 1962, 153-155.(A-19)

(d) Wolman, M. Gordon, "Problems Posed by Sediment Derived from Construction Activities in Maryland," Report to Maryland Water Pollution Control Commission, Annapolis, Maryland, January 1964, p. 125.(A-55)

(e) Diseker, E. G., and Richardson, E. C., "Control of Roadbank Erosion in the Southern Piedmont," Agronomy Journal, Vol. 53, 1961, 292-294. (A-13)

Purpose -

Determination of relative effectiveness of a number of straw mulching methods to control runoff and soil loss and the evaluation of plant establishment and survival.

Study-Site -

The four test sites were selected for the study in Oconee, Peach, and Wilkes counties in Georgia.

Period of Study -

From 1964 to 1965.

Slope and Soil Characteristics -

(a) Slope: (2.5:1) - 40%

(b) Soil Characteristics:

Oconee site - Cecil sandy loam
Peach site - Facereille sandy loam
Wilkes sites - Georgeville silty clay

Exhibit 237 represents the detailed analysis of soil constituents for each site.

Site Preparation and Treatment -

Plots of size 6 x 30 feet in size were prepared and each plot was graded to 2:1 slope and applied with 1,000 pounds of 8-8-8 fertilizer and 2 tons of lime per acre. This was followed by rototilling to a depth of 4 to 6 inches and seeding was done as follows:

(i) Oconee and Peach County Sites: seeded in the fall with 2 pounds of tall fescue grass, 20 pounds of Pensacola bahia grass, and 3 pounds of crownvetch per acre.

(ii) Wilkes County Sites: seeded in spring with 10 pounds of common Bermuda grass, 20 pounds of Pensacola bahia grass, and 3 pounds of Crown vetch per acre.

All plots were firmed with cultipacker after seeding. The treatment was done with grain straw at the rate of 2 tons per acre and the following treatments were applied.

1. Bare, no mulch
2. Surface-applied mulch in place with 200-500 gallons AE-5 asphalt per ton of straw
3. Mulch mixed in the previously tilled soil surface with a rotovator, then seeded and cultipacked

Exhibit 237. MECHANICAL ANALYSIS OF PLOT SURFACE SOILS AT THE TEST LOCATIONS

Treat-ment No.	Rep 1[a] Oconee County			Rep 2[a] Peach County			Rep 3[a] Wilkes Co. (1)			Rep 4[a] Wilkes Co. (2)		
	% Sand	% Silt	% Clay	% Sand	% Silt	% Clay	% Sand	% Silt	% Clay	% Sand	% Silt	% Clay
1	57	17	26	64	5	31	15	28	57	39	27	34
2	55	15	30	64	5	31	15	30	55	29	30	41
3	57	15	28	66	5	29	16	30	54	29	28	43
4	55	15	30	67	5	28	25	27	48	28	28	44
5	53	16	31	66	2	32	34	28	38	26	32	42
6	52	15	33	62	4	34	34	28	38	29	30	41
7	53	16	31	64	4	32	32	34	34	31	29	40
8	57	13	30	57	5	38	35	28	37	32	29	40
Avg	55	15	30	64	4	32	26	29	45	30	29	41

[a] Textural classes: Rep 1 & 2, sandy clay loam; Rep 3 & 4, clay.

4. Simulated Florida method or "whisker dams" in which straw mulch is embedded or pressed into the prepared soil, using a 3-ft. diameter weighted roller equipped with blunt coulters spaced 8 to 12 inches apart, roller operated on the contour.
5. Simulated California method, which is similar to treatment 4 except the coulters are replaced with blunt stubs that are staggered along alternate rows (These stubs punch the mulch into the prepared soil about 12 inches apart in a checkered pattern).
6. Mulch mixed into the prepared soil surface with a rotovator, then seeded and cultipacked followed by an application of AE-5 asphalt at the rate of 200 to 250 gallons per ton of straw. (Hot asphalt from an asphalt truck was applied with a standard patch nozzle. Precision was limited due to the hand application technique used and to the fact that no precise method was available for controlling the application rate on small plots.)
7. Standard Cartersville method: surface-applied mulch after planting and cultipacking.

Simulated Rainfall Data -

The intensity of the test storm was 2-1/2 iph in two increments of 30 minutes each with 10-minute interval of no rain in between. Actually, in accordance with the geographic region of the test sites, the first increment of 1-1/4 inches in 30 minutes represents the 1-year frequency storm and the entire intensity of 2-1/2 inches represents 10-year frequency storm. The second increment of 1-1/4 inches alone represents a 1-year frequency storm under very wet antecedent soil moisture conditions.

Results -

Exhibit 238 presents the summary of results for all four sites. It is apparent from the results that for the first rainfall, increment average runoff and soil loss for all mulch treatments were 0.23 inch (17%) and 3.4 tons per acre, respectively, compared with 0.50 inch (38%) of rainfall and 20.2 tons per acre for no mulch treatment. For total simulated storms, the soil losses from bare untreated and best mulched treatment were 97 tons and 10 tons per acre respectively. In all cases where asphalt spray was used as part of treatment, the effectiveness of mulch was decreased due to less impendance to overland flow and erosion taking place under the straw mulch canopy, showing that the asphalt had no beneficial effect. The results also showed that the Florida method (Treatment 4) was the best treatment and Treatment 7, the Cartersville method, was second in rank. Exhibit 239 represents the stand cover evaluations made on March 2-3 and November 1-2, 1965. Stand reflects the success of various mulch treatments during the early stages of growth, and cover is indicative of durability of the mulch and the cover provided by the plants themselves.

Discussion -

It is well known that the rate of annual soil loss on bare and unprotected roadcuts and highway ditches reaches alarming proportions, causing great damage to water bodies. Separate studies made by Diseker and Richardson (Source references A-13, A-14, and A-15), show the erosion rates as great as 300 tons per acre per year. Wolman reports erosion rates from an acre of ground under construction in developments and highways may exceed 20,000 to 40,000 times the amount eroded from farms and woodland in an equal period of time.(A-55) It is clear that unless some preventive measures are taken against soil erosion, there can be destruction of natural beauty and creation of unsightly terrain and hazardous driving conditions in addition to the serious loss of soil to water bodies. These studies made in middle and northeast Georgia also report that adaptable

Exhibit 238. SUMMARY OF RAINFALL, RUNOFF, AND SOIL LOSS AT TEST LOCATIONS

Treatment No.	Treatment	Incr. no.	Oconee County (Rep 1)			Peach County (Rep 2)			Wilkes County (Rep 3)			Wilkes County (Rep 4)			Means		
			Rainfall	Runoff	Soil loss	Rainfall	Runoff	Soil loss	Rainfall	Runoff	Soil loss	Rainfall	Runoff	Soil loss	Rainfall	Runoff	Soil loss
			in.	in.	t/ac	in.	in.	t/ac	in.	in.	t/ac	in.	in.	t/ac	in.	in.	t/ac
1	Bare, no mulch	1	1.36	0.74	23.43	1.32	0.49	36.07	1.31	.28	4.20	1.33	.50	16.94	1.33a	.50a	20.16a
		2	1.29	1.00	86.54	1.32	1.10	85.95	1.37	1.24	75.25	1.38	1.23	57.88	1.34a	1.14a	76.41a
		Tot.	2.65	1.74	109.97	2.64	1.59	122.02	2.68	1.52	79.45	2.71	1.73	74.82	2.67a	1.64a	96.57a
5	Calif. method ("checkered dams")	1	1.33	0.26	1.49	1.24	0.13	3.82	1.43	0.03	0.16	1.32	0.31	5.14	1.33a	0.18b	2.65b
		2	1.28	1.00*	30.78	1.26	0.90	32.42	1.45	0.77	55.03	1.38	1.43	46.10	1.35a	1.03ab	41.08b
		Tot.	2.61	1.26	32.26	2.50	1.03	36.24	2.91	0.80	55.19	2.70	1.74	51.24	2.68a	1.21b	44.48b
2	Surface mulch + asphalt	1	1.41	0.30	2.00	1.40	0.28	11.14	1.20	0.00	0.00	1.33	0.48	6.24	1.31a	0.27b	4.85b
		2	1.29	1.13	10.42	1.36	1.06	55.33	1.26	0.64	15.53	1.39	1.11	25.50	1.33a	0.99ab	26.69bc
		Tot.	2.70	1.43	12.42	2.78	1.34	66.47	2.46	0.64	13.53	2.72	1.59	31.74	2.67a	1.26b	31.54bc
3	Mulch mixed in surface	1	1.38	0.39	1.08	1.39	0.20	5.01	1.31	0.02	0.73	1.34	0.37	11.34	1.36a	0.25b	4.55b
		2	1.39	1.06	4.45	1.47	0.96	34.78	1.20	0.96	22.30	1.43	1.30	28.80	1.37a	1.07ab	22.59c
		Tot.	2.77	1.45	5.53	2.86	1.16	39.79	2.51	0.98	23.03	2.77	1.67	40.14	2.73a	1.32b	27.14bc
6	Mulch mixed in surface + asphalt	1	1.33	0.15	0.18	1.33	0.05	1.53	1.27	0.46	5.83	1.42	0.43	11.34	1.34a	0.27b	4.72b
		2	1.55	0.83	10.14	1.29	0.81	10.68	1.48	1.18	29.79	1.42	1.13	40.87	1.43a	0.99ab	22.97c
		Tot.	2.88	0.98	10.32	2.62	0.86	12.21	2.75	1.64	35.62	2.84	1.56	52.21	2.77a	1.26b	27.59bc
4	Florida method ("whisker dams")	1	1.38	0.27	1.64	1.39	0.19	4.79	1.31	0.00	0.00	1.34	0.39	3.03	1.36a	0.21b	2.37b
		2	1.37	0.92	9.21	1.47	0.54	9.39	1.20	0.89	2.71	1.43	1.24	8.76	1.36a	0.60b	7.31c
		Tot.	2.75	1.19	10.85	2.86	0.73	14.18	2.51	0.89	2.71	2.77	1.63	11.79	2.72a	1.11b	9.88c
7	Surface mulch (Cartersville)	1	1.33	0.31	1.83	1.33	0.01	0.33	1.27	0.09	0.28	1.42	0.34	2.10	1.34a	0.19b	1.14b
		2	1.55	1.14	6.52	1.29	0.79	9.14	1.48	0.70	6.28	1.42	1.02	18.32	1.43a	0.91b	10.06c
		Tot.	2.88	1.45	8.35	2.62	0.80	9.47	2.75	0.79	6.56	2.84	1.36	20.42	2.77a	1.10b	11.20c
Mean		1	1.36a	0.39a	6.98ab	1.34a	0.23b	12.35a	1.30a	0.15b	1.93b	1.36a	0.42a	9.14ab			
		2	1.39a	1.01b	30.58a	1.35a	0.91b	40.46a	1.35a	0.95b	35.65a	1.40a	1.21a	35.51a			
		Tot.	2.75a	1.40a	37.46a	2.69a	1.14b	52.81a	2.65a	1.10b	37.58a	2.76a	1.63a	44.65a			

* Data in the same row, column and increment followed by different lowercase letters are significantly different at the 5% level according to Duncan's multiple range tests.

Exhibit 239. COVER AND STAND EVALUATIONS ON MARCH 2-3 AND NOVEMBER 1-2, 1965

Treatment No.	Treatment	March 2-3, 1965				November 1-2, 1965			
		Oconee		Peach		Oconee	Peach	Wilkes(1)	Wilkes(2)
		St.	Cov.	St.	Cov.	Cov[a]	Cov[a]	Cov[b]	Cov[b]
		Percent							
1	Bare	48	10	30	4	30	25	40	75
6	Bare	7	1	18	3	10	50	90	40
5	California	37	15	77	22	40	98	95	45
2	Mulch + ashpalt	92	27	63	18	90	95	80	90
7	Mulch mixed + asphalt	28	4	65	27	80	95	85	90
3	Mulch mixed	77	23	75	20	80	75	95	95
8	Mulch (Cartersville)	87	25	88	37	95	100	95	50[c]
4	Whisker dams (Florida)	67	27	75	20	70	80	100	90

---

[a] Mostly fescue, som crownvetch, treatments 2 and 4. ı some

[b] Mostly common bermuda-grass with some bahiagrass on all plots.

[c] Unexplained bare area on upper half of this plot.

plants on properly fertilized areas can develop an effective cover which can control erosion on newly cut road banks and highway cuts to a great extent. The various measures for obtaining vegetative cover-growth are also applicable and beneficial to other similar slope conditions.

Case 40. Mulch Rates Required for Erosion Control on Steep Slopes

Source -

Meyer, L. D., Wischmeier, W. H., and Foster, C. R., "Mulch Rates Required for Erosion Control on Steep Slopes," Soil Science Society of America Proceedings, Vol. 34, No. 6, November - December 1970, pp. 928-931.(A-37)

Purpose -

"To determine the relative effectiveness of several rates of straw mulch on a steeply sloping soil of low permeability."

Site Description -

The soil used in this study was a moderately eroded Fox loam with a moderate to slow permeability. The plots 3.7 m wide and 10.7 m long, inclined at a 15% slope. Rainfall was provided by a machine called a Rainulator at a uniform intensity of 6.35 cm (2.5 inches) per hour for an initial run of 50 minutes and two 30-minute runs at 15-minute intervals.

Study Method -

Five different mulch rates were studied with two duplicate series of plots. The rates were 0, 0.56, 1.12, 2.24 and 4.48 metric tons per hectare (0, 1/4. 1/2. 1, and 2 English tons per acre). One of the duplicate series also contained a sixth plot which was treated with 8.96 M.T./ha. The portions of the soil surface that were physically covered by straw were 34, 49, 71, 92 and 95% for the five application rates.

Parameters Measured -

Soil loss, runoff and infiltration rates, and flow velocity from soil plots treated with 6 different application rates of straw mulch.

Results -
Exhibit 240 contains the averaged results for each application rate for each Rainulator run. The data indicates that even on steeply sloping soils of below average permeability, small amounts of straw mulch can cause considerable reductions of soil loss. 0.56 MT/ha reduced the soil loss to less than one-third of the loss of the untreated plot under the storm conditions of this experiment.

The results of this study are compared to those from sililar studies in Exhibit 241 . It is apparent that as slope increases, more mulch is needed for similar erosion protection.

Exhibit 242 contains the runoff velocity data for similar studies. One of the mechanisms for the velocity decrease is the variation of the flow path as the water is forced to follow an indirect, winding route through the straw. This is especially true for high loading rates.

The referenced paper concludes that although several metric tons of straw mulch per hectare are desirable for a good erosion control program, smaller amounts may be beneficial for the reduction of erosion where larger amounts are not practical. Perhaps low rates of mulch can be supplemented with other control measures to provide an optimal economic solution.

Exhibit 240. EROSION, RUNOFF, AND INFILTRATION FOR RAINULATOR STUDY OF RATES OF STRAW MULCH°

Mulch rate†	Run‡	Soil loss§	Run-off¶	SL/RO ratio	Infiltration Total¶	Infiltration Rate**	Flow vel.††
MT/ha		MT/ha	cm	% by wt.	cm	cm/hr	cm/sec
0	All runs	62.3 a	8.7	7.2	4.0	1.4	13.9
0.56	All runs	20.1 b	7.6	2.6	5.1	1.7	7.1
1.12	All runs	19.4 b	8.3	2.3	4.4	1.4	6.9
2.24	All runs	11.5 bc	8.6	1.3	4.1	1.2	5.6
4.48	All runs	2.5 c	7.0	0.4	5.7	1.8	5.3
8.96	All runs	1.5	7.7	0.3	5.0	1.4	6.0
0	Initial	36.2 e	4.1	8.9	2.2	1.3	
0.56	Initial	9.9 f	3.1	3.1	3.2	2.2	
1.12	Initial	10.1 f	3.6	2.8	2.7	1.7	
2.24	Initial	6.2 g	3.8	1.6	2.5	1.6	
4.48	Initial	1.2 h	2.7	0.5	3.6	2.3	
8.96	Initial	0.9	3.0	0.4	3.3	2.1	
0	Wet	13.1 j	2.2	6.0	1.0	1.5	
0.56	Wet	5.1 k	2.2	2.4	1.0	1.4	
1.12	Wet	4.5 k	2.3	1.9	0.9	1.1	
2.24	Wet	2.4 km	2.3	1.0	0.9	1.1	
4.48	Wet	0.6 m	2.0	0.3	1.2	1.5	
8.96	Wet	0.4	2.2	0.2	1.0	1.0	
0	Very wet	13.0 p	2.4	5.5	0.8	1.4	
0.56	Very wet	5.1 q	2.3	2.2	0.9	1.6	
1.12	Very wet	4.8 q	2.4	2.0	0.8	1.3	
2.24	Very wet	2.9 qr	2.5	1.1	0.7	1.0	
4.48	Very wet	0.7 r	2.3	0.3	0.9	1.5	
8.96	Very wet	0.2	2.5	0.1	0.7	1.0	

* Plots were 3.7 by 10.7 m and averaged 15% slope. Values given are the averages of two replications, except the unreplicated 8.96-MT/ha rate.

† Mulch rates were 0, 1/4, 1/2, 1, 2, and 4 tons per acre, respectively.

‡ Initial runs were 60 min in duration; wet and very wet runs, 30 min each.

§ Adjusted to an application intensity of 6.35 cm/hr and 15% slope. Within each type of run, differences are significant at the 5% level if the same letter does not appear.

¶ Adjusted to an application intensity of 6.35 cm/hr. Total water applied was 12.7 cm.

** Average rate during the last 5 min of the runs.

†† Average velocity between 3.8 and 9.9 m downslope as determined visually by rate of dye advance.

Exhibit 241. EFFECT OF STRAW MULCH RATE ON EROSION RATE FOR SEVERAL CONDITIONS

Mulch rate	Soil loss for conditions indicated: Fox loam, unplowed, S=15% L=10.7m	Xenia silt loam, plowed & disked, S=3% L=10.7m (10)	Wea silt loam, plowed & disked, S=5% L=10.7m (7)	Laboratory study, 121μ spheres, L=12m (5): S=8%	S=10%
MT/ha	MT/ha	MT/ha	MT/ha	MT/ha	MT/ha
0	62.3	32.4	27.8	13.3	43.3
0.56	20.1	13.0	7.2	6.9	16.7
1.12	19.4	8.2	3.2	4.4	9.8
2.24	11.5	3.8	0.7	3.9	9.3
4.48	2.5	--	0	--	--
8.96	1.5	--	0	--	--

Exhibit 242. EFFECT OF STRAW MULCH RATE ON RUNOFF VELOCITY FOR SEVERAL CONDITIONS

Mulch rate	Velocity of flow for conditions indicated: Fox loam unplowed, S=15%	Xenia silt loam, plowed & disked, S=3% (10)	Laboratory study, 121μ spheres (5): S=6%	S=8%	S=10%
MT/ha	cm/sec*	cm/sec*	cm/sec†	cm/sec†	cm/sec†
0	13.9	13.1	15.6	17.1	19.4
0.56	7.1	6.9	8.3	8.9	12.3
1.12	6.9	6.3	6.9	6.9	10.1
2.24	5.6	3.4	5.9	5.9	7.5

* Average for plot section from 3.8 to 9.9 m downslope.

† Average for section from 9.0 to 12.0 m downslope.

Case 41. Stone and Woodchip Mulches for Erosion Construction Sites

Source -

Meyer, L. D., Johnson, C. B., and Foster, G. R., "Stone and Woodchip Mulches for Erosion Construction Sites," Journal of Soil and Water Conservation, Vol. 27, No. 6, November - December 1972, p. 264 ff.(A-36)

Purpose -

This study compares erosion rates for various application rates of straw, stone, gravel, woodchip and portland cement mulches in order to determine a cheap, effective erosion deterrent for exposed soils.

Site Description -

The experiment area was the sideslope of a borrow pit dug during construction of Highway I-65 near Dayton, Indiana. The soil was a compacted calcareous till underlying a Wingate silt loam. It's bulk density was 1.6 to 1.7 grams/cubic centimeter. Particle-size distribution was 12 percent coarse than 2 mm. (See Exhibit 243.)

Study Method -

Six inches of subsoil were spread over a uniform 20 percent slope. The surface was compacted, then released smooth. Sixteen 6-foot by 35-foot plots were laid out and covered with various mulches. Many of the mulches were run in duplicate and tests on several plots were repeated with larger application rates. In all, 20 tests were run on six types of mulch at 14 application rates.

Simulated rainfall was applied at a rate of 2-1/2 inches per hour for 1 hour on the first day and two 30-minute periods the following day. In addition, water was added uniformly across the high end of each plot to simulate longer slopes and their effects on mulch stability. The inflow was applied at rates equal to, twice and three times the runoff

Exhibit 243. Erosion Plots Following Rainstorm Applied by Rainulator. Four of Eight Plots in Group Were Tested Simultaneously.

rate anticipated from rainfall on a 35-foot plot. Runoff, erosion rates and flow velocities were determined on all tests.

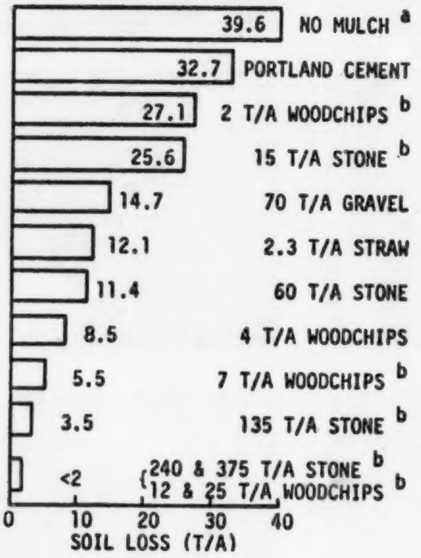
In September, after the testing was complete, the plots were seeded with approximately 30 lbs per acre of rye grass and fescue and 400 lbs per acre of 15-15-15 fertilizer. The plots weren't tilled and erosion damage was not repaired. They were left as they were at the completion of the testing. Weather during that period was relatively favorable for revegetation.

Results -

Exhibit 244 gives resulting soil losses from 5 inches of intense rainfall on the 35-foot plots. They fall into three groups. The best performances were by the high application rates of stone (>135 tons/acre) and woodchips (> 7 T/A). The middle group included 4 T/A woodchips, 60 T/A stone, 2.3 T/A wheat straw and 70 T/A gravel. The last group contained the lightest applications of stone and woodchips, Portland cement and no mulch.

The development of rills greatly influenced several of the treatments, especially in the last group where the rills grew to 4-6 inches deep. Rill development was much less pronounced in the middle group, except that the rills tended to form under the straw to allow unimpeded flow. The stone and gravel tended to settle in place and the woodchips were occasionally carried down slope. The plots with the highest application rates of stone and woodchips did not develop noticeable rills.

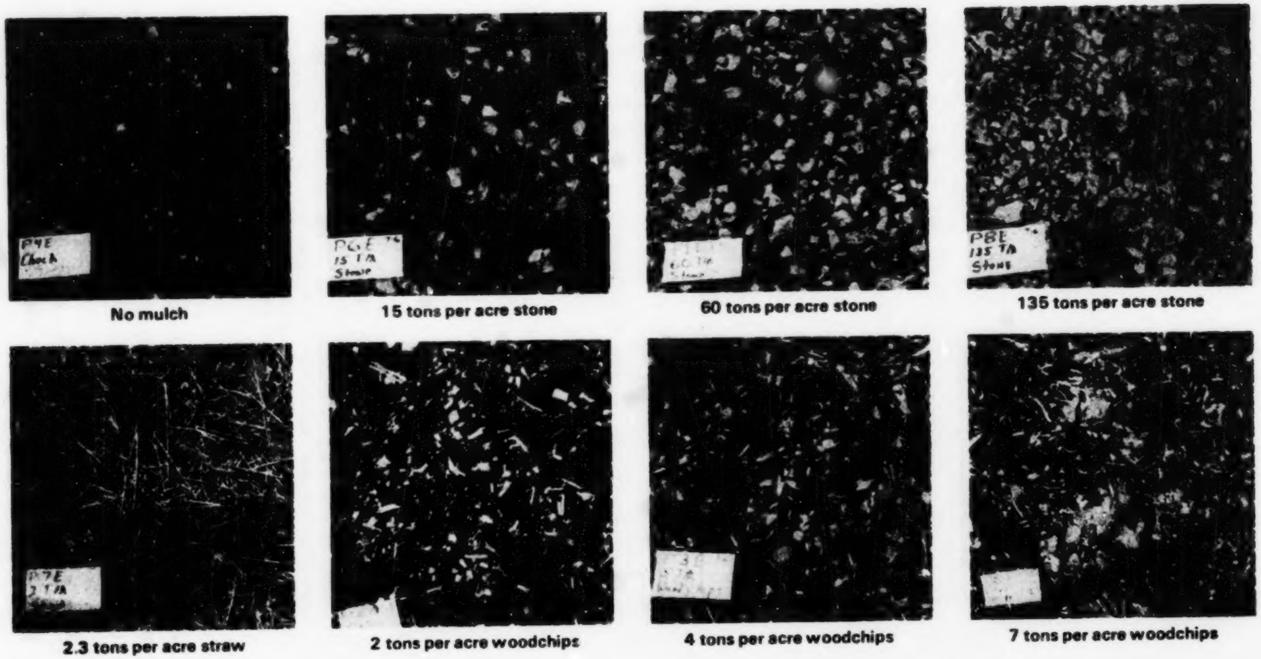
Exhibit 245 gives the results of the studies with inflow water added in addition to rainfall. Again, rilling developed on several of the plots. Once serious rilling began, mulch rate did not appreciably effect the erosion rates. Woodchip mulches were the most seriously



[a] Based on one replication only. The other no-mulch plot was severely damaged by erosion during a natural rainstorm when its cover was blown off. Repairs prior to testing apparently caused abnormally high erosion totaling 95.9 tons per acre. [b] Unreplicated treatment. Values for other treatments are averages for two replications.

Note: Rain Intensity, 2.5 inches per hour; slope length, 35 feet; slope steepness, 20 percent; soil, calcareous till beneath wingate silt loam.

Exhibit 244. Soil Losses from 5-inches of Simulated Rain on Denuded Slopes for Various Types and Rates of Mulch


P4E
Check
PGE
15 T/A
Stone
PBE
135 T/A
Stone
P7E
2 T/A

No mulch

15 tons per acre stone

60 tons per acre stone

135 tons per acre stone

2.3 tons per acre straw

2 tons per acre woodchips

4 tons per acre woodchips

7 tons per acre woodchips

Note: Actual straw and woodchip rates varied from those given on the 3 x 5-inch cards. Heavier rates of stone and woodchips (not pictured) provided complete cover.

Exhibit 245. Typical Treatments on a 20 Percent Denuded Slope

affected. When their breakdown point was reached, the slope rapidly deteriorated forming large deep rills. Perhaps anchoring them with some kind of emulsion may improve their effectiveness.

The most effective treatment studied was 135 tons per acre of stone mulch. This averages less than 1-inch deep and can be delivered and spread for about a penny per square foot. Woodchip mulch applied at a rate of 25 tons/acre was also quite effective. Woodchips can often be obtained at hauling costs. Stone, gravel and woodchips are also more resistant to being blown away than straw.

Flow velocities are tabulated in Exhibit 246. They tend to correspond closely with the erosion rates in that mulches effective against erosion also reduce runoff flow velocities. Rilling had similar results in that once rills become established, runoff rates increased. Stones and gravel tended to inhibit rill flow although erosion still occurred. Prior to rilling, high rates of woodchips were the most effective retardant, probably due to smaller pores in the mulchis mass.

Revegetation was evaluated the following spring. The plots with the best cover were those with 240 and 135 T/A stone, 12 T/A woodchips, gravel and straw mulch. The grass appeared healthiest and yellowish on the woodchip and straw plots. Considerable amounts of grass grew through the thickest layers of stone and woodchips (2-1/2 and 1-1/2 inches respectively). The plots with deep rills developed their best grass in the rills.

Conclusions -

The authors ranked the most effective treatments for the different slope lengths on a 20 percent slope. Their list is presented in Exhibit 247. Stone mulch at 240 tons/acre is one of the most effective treatments at every length. Other effective treatments include 135 tons/acre of stone and 12 and 25 tons/acre of woodchips. These are all relatively cheap

Exhibit 246. FLOW VELOCITIES AT VARIOUS DISTANCES DOWNSLOPE (SLOPE STEEPNESS, 20 PERCENT; RAIN INTENSITY, 2.5 INCHES PER HOUR).

Treatment	*Average Velocities (ft/sec)*			
	12 to 32 ft Section	*55 to 75 ft Section*[a]	*95 to 115 ft Section*[a]	*140 to 160 ft Section*[a]
No mulch	0.67[b]	1.20[b]	1.58[b]	1.62[b]
Straw				
2.3 tons/a	.32	.42	.47	.46
Stone				
15 tons/a	.51[b]	.83[b]	1.13[b]	1.36[b]
60 tons/a	.32	.50	.59	.65
135 tons/a	.18	.31	.40	.46
240 tons/a	.18	.29	.36	.43
375 tons/a	.16	.22	.26	.27
Gravel				
70 tons/a	.30	.50	.60	.72
Woodchips				
2 tons/a	.41[b]	.96[b]	1.48[b]	1.62[b]
4 tons/a	.22	.52	.72	1.20[b]
7 tons/a	.23	.60	1.21[b]	1.50[b]
12 tons/a	.09	.14	.21	.42[c]
25 tons/a	.16	.17	.18	.18
Portland cement	.46[b]	.65[b]	.98[b]	1.50[b]

[a] Obtained by adding inflow to produce flow approximately equivalent to runoff from 2½-inch-per-hour rainfall application at the distances downplot shown.

[b] Severe rilling caused flow to occur in rills rather than across mulched areas.

[c] Before breakdown; see note d of table 2.

Exhibit 247. RATING FOR EROSION CONTROL EFFECTIVENESS ON DENUDED SLOPE OF 20 PERCENT STEEPNESS (BEST TO WORST)[a]

Slopes less than 40 feet long
- ≥ 240 tons/a stone; ≥ 12 tons/a woodchips
- 135 tons/a stone
- 7 tons/a woodchips
- 4 tons/a woodchips
- 60 tons/a stone and gravel; 2.3 tons/a straw

Slope lengths of 40 to 100 feet
- ≥ 240 tons/a stone; 25 tons/a woodchips
- 12 tons/a woodchips
- 135 tons/a stone

Slope lengths of 100 to 160 feet
- ≥ 240 tons/a stone; 25 tons/a woodchips
- 135 tons/a stone

---

[a] Other treatments were much less effective in reducing erosion.

and easy to apply. In addition they can later be seeded and produce good stands of grass. These treatments can be applied following reshaping to provide immediate protection in construction areas.

Case 42. An Economic Analysis of Erosion and Sediment-Control Methods for Watersheds Undergoing Urbanization

Source -

Brandt, Gerald H., et al., An Economic Analysis of Erosion and Sediment-Control Methods for Watersheds Undergoing Urbanization, W72-08246, The Dow Chemical Co., 191P, February 1972, PB-209-212.(A-7)

Purpose -

To compare cost and effectiveness of erosion and sediment control systems.

Site Description -

Two sub-basins in the Seneca Creek watershed in Montgomery County, Maryland were chosen for study: see Exhibits 248 and 249. A 2003 acre segment near Gaithersburg, Maryland was undergoing urbanization. Its 1970 land use consisted of:

	Acres
Grassland	1,035
Urban	380
Urbanizing	241
Woodland	237
Cropland	60
Lakes	50
	2,003

This area's topography is predominately made up of gently rolling hills with an elevation ranging from 310 to 480 feet above sea level. The basin includes part of Montgomery Village, a new town being constructed in the area. The village is growing at a rate of 1000 people per year.

The second study area was a 1,960-acre segment near Germantown. This area was not subject to construction activities, although plans have been made for its future urbanization. It was included for use as a

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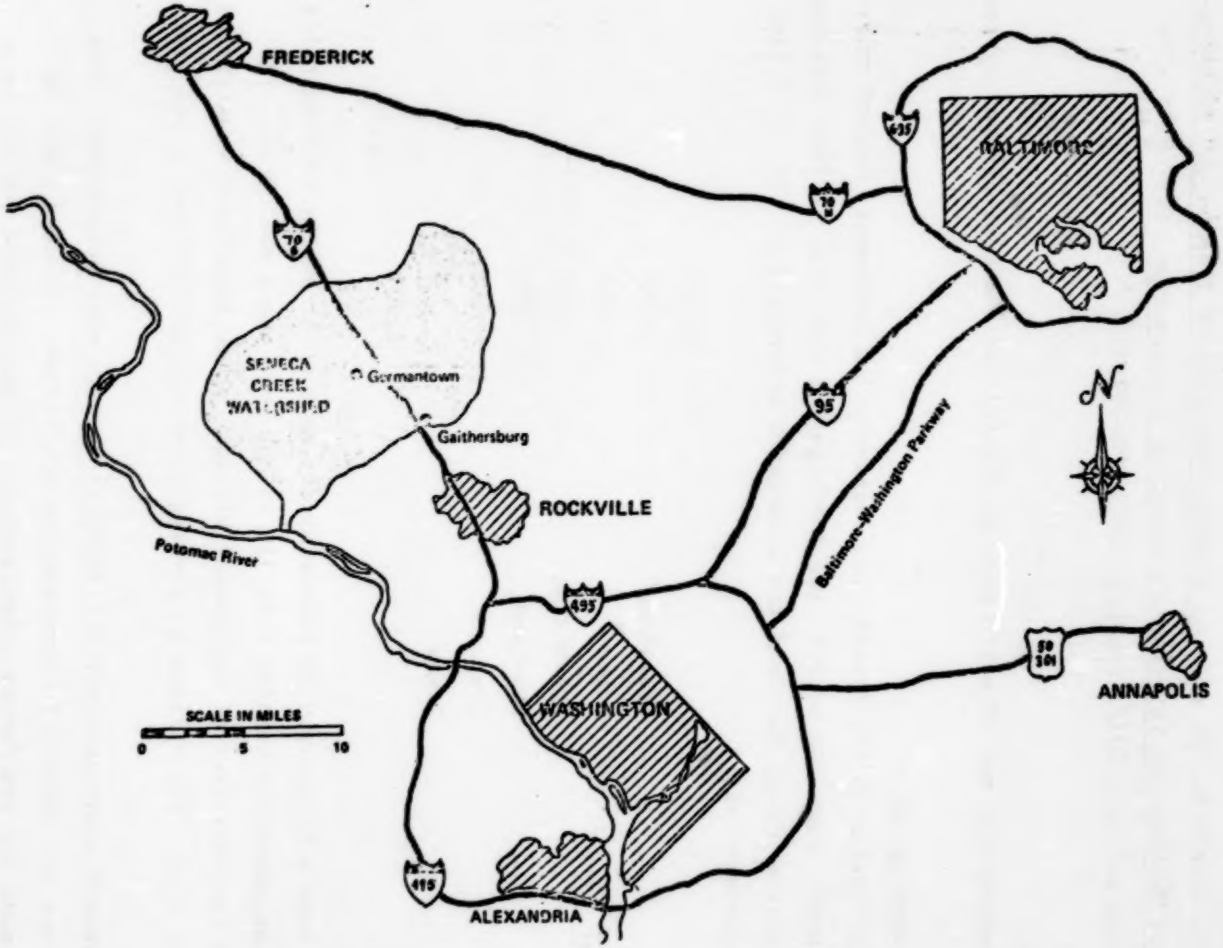
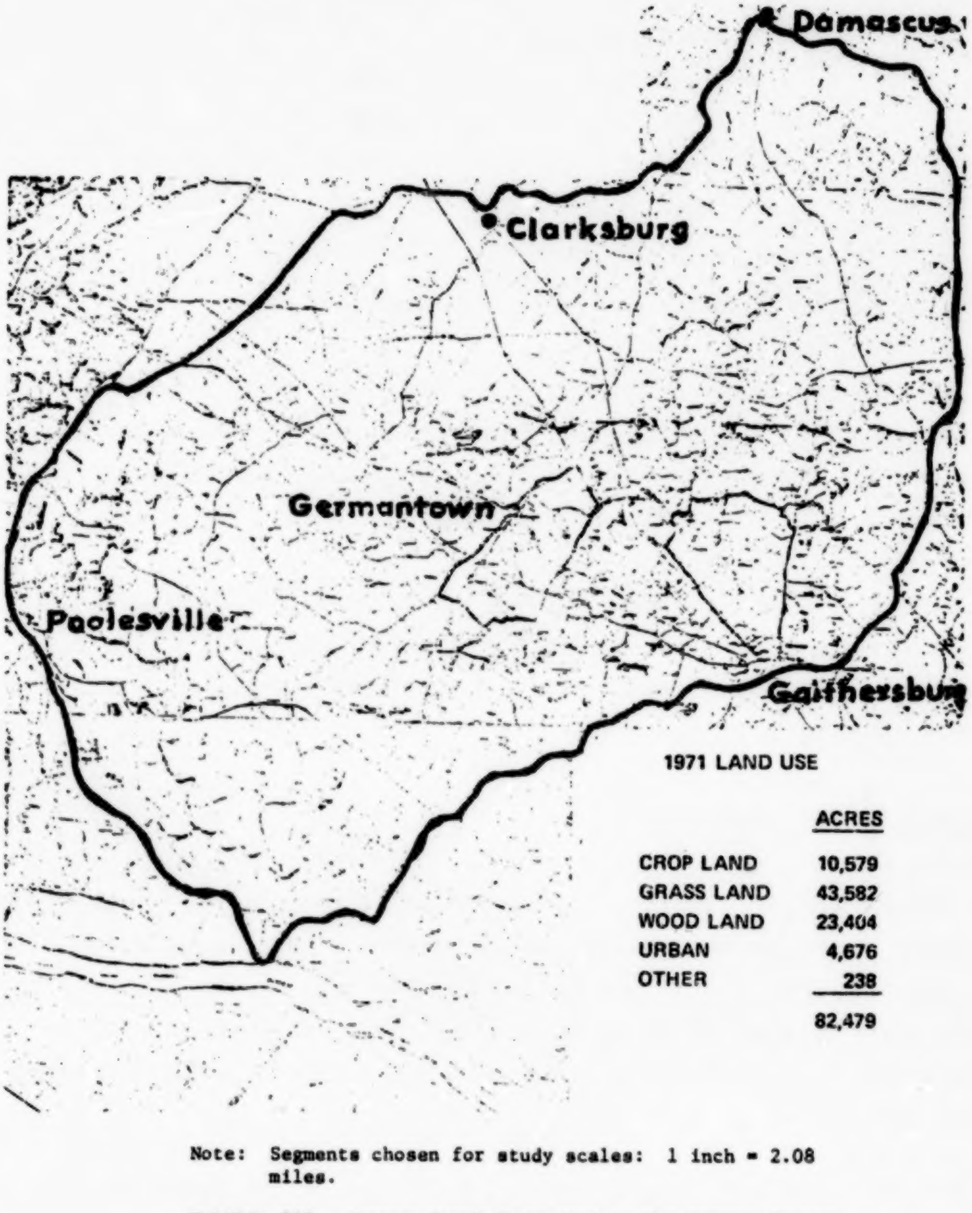

FREDERICK
70
695
70
BALTIMORE
SENECA
CREEK
WATERSHED
Germantown
Gaithersburg
ROCKVILLE
95
Baltimore-Washington Parkway
N
Potomac River
495
50
301
ANNAPOLIS
SCALE IN MILES
0
5
10
WASHINGTON
495
ALEXANDRIA

Exhibit 248. Location of Seneca Creek Watershed With Respect to Major Surrounding Metropolitan Areas


Damascus
Clarksburg
Germantown
Poolesville
Gaithersbu

1971 LAND USE

	ACRES
CROP LAND	10,579
GRASS LAND	43,582
WOOD LAND	23,404
URBAN	4,676
OTHER	238
	82,479

Note: Segments chosen for study scales: 1 inch = 2.08 miles.

Exhibit 249. Seneca Creek Watershed in Montgomery County, Maryland, Showing Land Use Distribution, Major Population Centers and Location of Watershed

test basin for the control methods developed in this study. Its land use was broken down as follows:

	Acres
Grassland	987
Cropland	258
Woodland	480
Urban	235
Urbanizing	0
	1,960

The elevation ranges from 280 to 520 feet.

The 1970 population of this area was less than 1000, but is expected to rise to 20,000 by the year 2000. This area is planned to contain a core of high-rise office buildings, apartments and shopping centers surrounded by residential communities.

The soils of both segments consist of the Glenelg and Manor series. The Glenelg is a deep well-drained soil developed from a soft mica-schist. The Manor series is rather shallow, excessively drained, and has a poorly developed subsoil.

Study Method, Results -

Sediment Yield - After selecting the watershed and the two study segments, their sediment yields were estimated using the Universal Soil Loss Equation. The K* values used for the soil erodibility were those of the A horizon of the soils involved. The other factors in the equation were either taken from published tables or estimated based on established practice.

---

*The K, C and P factors refer to the factors of the Universal Soil Loss Equation. See Section VI.

After determining the amount of soil eroded with the soil loss equation, the results were multiplied by a sediment delivery ratio based partly on the work of Roehl.(A-42) This ratio adjusted the computed yield to account for intermediate deposition.

Both basins were subdivided into small segments of relatively consistant land use and soil characteristics. The sediment yields of each segment were computed and tabulated by land use. It was assumed that construction activities were uncontrolled sources (C=P=1.0). These results were compared with the effects of controlling construction sedimentation to varying degrees (see Exhibits 250 to 252).

Gross erosion from the Gaithersburg segment with no sediment control measures taken in the construction area was 50,700 tons/year. Of this amount, 43,300 tons were due to construction activity on 241 acres, a rate of 188 ton/acre/year. The yield for the rest of the basin averaged 3 tons/acre/year. Net erosion, or the amount of sediment that reaches the stream, was determined by multiplying the gross erosion values by a sediment delivery ratio of .39. The use of a 90% effective erosion control program would reduce the net sediment yield from an average uncontrolled rate of 9.9 tons/acre/year to 1.9 tons/acre/year.

Since the Germantown segment was undergoing a construction activity, its yield was about 1 ton/acre/year, or approximately the same as the non-construction areas of the Gaithersburg segment. The effects of uncontrolled construction in this basin could increase the sediment output by a factor of 10.

Control Measures - Standard control measures were in use in the Gaithersburg segments. These measures included diversion and interceptor berms, sodded ditches, grade stabilization structures, level

Exhibit 250. GROSS EROSION WITHIN THE GAITHERSBURG SEGMENT ASSUMING NO SEDIMENT AND EROSION CONTROL ON CONSTRUCTION AREAS (FACTOR C VALUE = 1)

Land Use	Acres	Gross Erosion (Ton/Year)	Percent of Erosion
Construction	241	45,347	89.4
Cropland	60	596	1.2
Grassland	1,035	3,242	6.4
Woodland	237	328	0.6
Urban	380	1,218	2.4
Nonsediment contributing	50	0	0.0
Total	2,003	50,731	100.0

Exhibit 251. IMPACT OF CONTROLLING EROSION AND SEDIMENT FROM URBAN CONSTRUCTION IN THE GAITHERSBURG SEDIMENT

Degree of Control	Construction (Ton/year)	All Sources (Ton/year)	Construction Contribution (Percent)	Sediment Yield* (Ton/mile² year)
0	45,347	50,731	89.4	6,322
50	22,673	28,057	80.8	3,495
75	11,337	16,721	67.6	2,083
90	4,535	9,919	45.7	1,236
95	2,267	7,651	29.6	953

*Assumes sediment delivery ratio of 39%.

Exhibit 252. GROSS EROSION WITHIN GERMANTOWN SEGMENT

Land Use	Acres	Gross Erosion (Ton/year)	Percent of Erosion
Cropland	258	2,270	45.6
Grassland	987	1,817	36.5
Urban	235	389	7.8
Woodland	480	505	10.1
Total	1,960	4,981	100.0

spreaders and sediment basins. Seven representative plans were analyzed. Exhibit 253 gives the range and number of structures on an average acre of the 241 acre construction area. All cost and effectiveness analysis was based on the average acre.

In addition, variations of current practices were considered (shown in Exhibit 254. System number 10 corresponds to the conventional treatment shown in Exhibit 253. Systems 11 to 15 differ from 10 only in the method of surface stabilization. System 16 eliminates surface stabilization. Systems 20 through 26 eliminate sodded ditches, grade stabilization structures and level spreaders. Systems 30 through 36 rely on a 6-month waiting period after seeding to allow grass to become established before building activity. The cost of the two chemical treatments are: type A - $150 per acre, and type B - $250 per acre. Both are generally effective for only a few months.

For the Germantown segment, more innovative control measures were examined. These included a third erosion control chemical, chemical straw tacking, downstream sediment basins with and without flocculants and grading variations such as strip or spot building. The various combinations are listed in Exhibit 255.

Chemical X* costs $150 per acre and is effective for about one year. The chemical straw tacking is substituted for the more conventional asphalt emulsion or disking methods of anchoring the mulch. Special building practices including strip, spot and natural terrain building reduce the amount of exposed area, but impose a high price on the resulting buildings.

The effectiveness of these various treatments was again estimated with the Universal Soil Loss Equation by assigning each surface treatment combination a C-factor value (listed in Exhibit 256). Similarly,

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*The specific chemical is not identified, but properties are assumed. See Exhibit 255.

Exhibit 253. WEIGHTED AVERAGE AND RANGE OF EROSION AND SEDIMENT CONTROL STRUCTURES FROM SEVEN GAITHERSBURG PLANS

Structures	Range	Weighted Average
Diversion Berms	12-162 ft/acre	101 ft
Interceptor Berms	0- 31 ft/acre	12 ft
Sodded Ditches	3-103 ft/acre	37 ft
Grade Stabilization	1- 22 ft/acre	8 ft
Level Spreaders	0- 13 ft/acre	5 ft
Sediment Basins	0-.07/acre	.04/acre

Exhibit 254. EROSION AND SEDIMENT CONTROL ALTERNATIVES FOR THE GAITHERSBURG SEGMENT

System Number	Surface Stabilization				Time Between Seeding & Building		Erosion Reducing Structures		Diversion Berms	Sediment Basins		Effectiveness %
	Seed & Fertilizer	Straw Mulch	Chemical		None	6 Months	Normal	High		.04/Acre	.06/Acre	
			A	B								
10	✓	✓			✓		✓			✓		91
11	✓				✓		✓			✓		84
12			✓		NA		✓			✓		78
13				✓	NA		✓			✓		78
14	✓		✓		✓		✓			✓		87
15	✓			✓	✓		✓			✓		87
16					✓		✓			✓		75
20	✓	✓			✓				✓		✓	90
21	✓				✓				✓		✓	81
22			✓		NA				✓		✓	73
23				✓	NA				✓		✓	73
24	✓		✓		✓				✓		✓	84
25	✓			✓	✓				✓		✓	84
26					NA				✓		✓	70
27	✓	✓			✓			✓				86
28					NA			✓				60
29	✓	✓			✓							65
30	✓	✓				✓	✓			✓		94
31	✓					✓	✓			✓		87
32	✓		✓			✓	✓			✓		91
33	✓			✓		✓	✓			✓		91
34	✓	✓				✓			✓		✓	93
35	✓	✓				✓		✓				91
36	✓	✓				✓						77

Exhibit 255. EROSION AND SEDIMENT CONTROL ALTERNATIVES FOR GERMANTOWN

System Number	Surface Stabilization				Erosion Reducing Structures ·Normal	On-Site Sediment Basins .04/Acre	Downstream Sediment Basins		Strip Building	Effectiveness %
			Chemical System							
	Seed & Fertilizer	Straw Mulch	Straw Tack	X			Normal	With Flocculant		
10	░	░			▨	▤				91
17				░	▨	▤				84
18	░			░	▨	▤				90
19	░	░	░		▨	▤				91
40	░	░					●			93
41	░						●			87
42				░			●			87
43	░			░			●			92
50	░	░						●		96
51	░							●		94
52				░				●		94
53	░			░				●		96
60	░	░			▨	▤			▒	93
61	░	░						●	▒	97
70	Natural Terrain Building									(see text)
80	░	░			▨	▤	[with spot building]			(see text)

Exhibit 256. AVERAGE FACTOR C VALUES FOR VARIOUS SURFACE STABILIZING TREATMENTS

Treatment	Factor C Values Time Elapsed Between Seeding and Building None*	 6 Months**
Seed, fertilizer and straw mulch. Straw disked or treated with asphalt or chemical straw tack.	0.35	0.23
Seed and fertilizer	0.64	0.54
Chemicals A and B	0.89	--
Seed and fertilizer with Chemicals A and B	0.52	0.38
Chemical X	0.56	-
Seed and fertilizer with Chemical X	0.38	-

*Assumes 18-month construction period.
**Assumes 24-month construction period.

control structures were assigned the P-factor values listed in Exhibit 257. The combined system effectiveness was determined using an equation derived from the soil loss equation:

$$\% \text{ effectiveness} = (1 - CP) \times 100$$

The effectiveness of the various treatments is listed in Exhibit 253 and 255. The conventional practices were estimated to be 91% efficient under active construction while systems incorporating downstream impoundments and chemical flocculation ranged from 94 to 97%.

Costs - The unit cost of the control structures is listed in Exhibit 258. The cost of plan design and approval was averaged to $34 per acre. Field engineering costs were assumed to be 5% of the structure cost. The structure costs for the seven conventional plans analyzed in the control section ranged from $180 to $780 per acre, with a weighted average of $420 per acre, resulting in a design and engineering cost of $55 per acre. Property value was placed at $5000 per acre. Taxes were computed to be $144 per acre per year in the graded state. Seeding fertilizer and mulch bring the total treatment cost for the conventional control system to $976 per acre. Surface stabilizing costs are listed in Exhibit 259.

Two further costs are estimated. Maintenance costs include the dredging of sediment basins, erosion damage and restoration. This cost was estimated through contacts with developers and contractors. Some sediment escapes all interception mechanisms and eventually ends up in the stream and, in this case, the Potomac River. The damaged areas include metropolitan water supply, electric power, dredgings, commerical fishing, recreational fishing, boating, flood relief and esthetics. The estimated results come to a total of $6.80 per ton of sediment. The breakdown is given in Exhibit 260. Damages to the stream and river below the two study areas were estimated at $1,500 per acre undergoing construction.

Exhibit 257. FACTOR P VALUES FOR COMPONENTS OF EROSION AND SEDIMENT CONTROL SYSTEMS

Component	Factor P Value
(1) Small sediment basin:	
0.04 basin/acre	0.50
0.06 basin/acre	0.30
(2) Downstream sediment basin:	
With chemical flocculants	0.10
Without chemical flocculants	0.20
(3) Erosion reducing structures:	
Normal rate usage	0.50
High rate usage	0.40
(4) Strip building	0.75

Exhibit 258. ESTIMATE DEVELOPER COSTS FOR EROSION CONTROL STRUCTURES

Structure	Cost
Diversion berms	$1.25/linear foot
Interceptor berms	$1.25/linear foot
Sodded ditches	$4.50/linear foot
Grade stabilization structure	$2.80/linear foot
Level spreader	$2.80/linear foot
Small sediment basin	$1,500 each

Exhibit 259. COSTS FOR SURFACE STABILIZING TREATMENTS

Treatments	$/Acre
None	0
Seed, fertilizer, mulch	500
Seed only	209
Chemical A	300
Chemical B	387
Chemical X	300
Seed, fertilizer, Chemical A	480
Seed, fertilizer, Chemical B	567
Seed, fertilizer, Chemical X	480
Seed, fertilizer and straw tack	493

Exhibit 260. SUMMARY OF DAMAGES IN POTOMAC BELOW SENECA CREEK

	K $/Year	$/Ton of sediment
Metro water supply	246	.31
Industrial		
Electric power cooling	0	—
Dredging	520	.67
Commercial fishing	990	1.27
Recreational		
Fishing	692	.88
Boating	653	.84
Aesthetics	2,000	2.56
SUBTOTAL	5,101	6.53
Flood damage abatement benefit accrued to impoundments		.27
TOTAL		6.80

Exhibits 261 and 262 give the cost breakdowns for the various control systems. Note that control costs are significantly lower than the damage cost of uncontrolled construction. The treatment systems incorporating spot strip and natural terrain building were eliminated due to prohibitive construction costs. Exhibit 263 compares the cost and effectiveness for the most promising of the control systems under study. For the Gaithersburg segment the conventional system is recommended for continued use, with system 20 as an adequate alternative. System 20 incorporated fewer structural diversions but larger sediment basins than the conventional plan. Of the more advanced treatments considered for the Germantown segment, the most beneficial were the systems incorporating downstream sediment basins. These gave high efficiencies and trapped sediment from sources other than the construction area alone.

Exhibit 261. EROSION AND SEDIMENT CONTROL ALTERNATIVES FOR GAITHERSBURG SEGMENT WITH COSTS

System Number	Surface Stabilization				Time Between Seeding & Building		Erosion Reducing Structures		Diversion Berms	Sediment Basins		Effectiveness %	Treatment Costs, $/Acre					Maintenance Costs $/Acre Construction Period			Sediment Damages To Stream $/Acre	Residual Value $/Acre	Grand Total $/Acre/ Construction Period
	Seed & Fertilizer	Straw Mulch	Chemical		None	6 Months	Normal	High		04/Acre	06/Acre		Structures & Berms	Engineering	Surface Stabilization	Interest Tax	Rounded Total	Sediment Basins	Erosion Damage & Restoration	Total			
			A	B																			
10	░	░			▨		▤			▒		91	421	55	500	–	975	50	100	150	130	-100	1,155
11	░				▨		▤			▒		84	421	55–	209	–	685	90	150	240	235	-100	1,060
12			░		NA		▤			▒		78	421	55	300	–	775	125	200	325	320	–	1,420
13				░	NA		▤			▒		78	421	55	387	–	865	125	200	325	320	–	1,510
14	░		░		▨		▤			▒		77	421	55	480	–	955	75	125	200	190	-100	1,245
15	░			░	▨		▤			▒		77	421	55	567	–	1,045	75	125	200	190	-100	1,335
16					▨		▤			▒		75	421	55	–	–	475	140	300	440	365	–	1,280
20	░	░			▨				●		▒	90	234	37	500	–	770	140	200	340	145	-100	1,155
21	░				▨				●		▒	81	234	37	209	–	480	255	250	505	275	-100	1,160
22			░		NA				●		▒	73	234	37	300	–	570	350	300	650	395	–	1,615
23				░	NA				●		▒	73	234	37	387	–	660	350	300	650	395	–	1,705
24	░		░		▨				●		▒	84	234	37	480	–	750	205	225	430	235	-100	1,315
25	░			░	▨				●		▒	84	234	37	567	–	840	205	225	430	235	-100	1,405
26					NA				●		▒	70	234	37	–	–	270	390	300	690	440	–	1,400
27	░	░			▨			▤				86	467	62	500	–	1,030	–	100	100	205	-100	1,235
28					NA			▤				60	467	62	–	–	530	–	300	300	585	–	1,415
29	░	░			▨							65	–	16	500	–	515	–	200	200	510	-100	1,125
30	░	░				▨	▤			▒		94	421	55	500	337	1,315	30	125	155	115	-100	1,485
31	░					▨	▤			▒		87	421	55	209	328	1,315	100	190	290	255	-100	1,760
32	░		░			▨	▤			▒		91	421	55	480	340	1,295	70	155	225	175	-100	1,595
33	░			░		▨	▤			▒		91	421	55	567	344	1,385	70	155	225	175	-100	1,685
34	░	░				▨			●		▒	93	234	37	500	332	1,105	90	250	340	135	-100	1,480
35	░	░				▨		▤				91	467	62	500	342	1,370	–	125	125	175	-100	1,570
36	░	░				▨						77	–	16	500	321	835	–	250	250	450	-100	1,435

Exhibit 262. EROSION AND SEDIMENT CONTROL ALTERNATIVES FOR GERMANTOWN SEGMENT WITH COSTS

System Number	Surface Stabilization				Erosion Reducing Structures Normal	On-Site Sediment Basins .04/Acre	Downstream Sediment Basins		Strip Building	Effectiveness %	Treatment Costs, $/Acre				Maintenance Costs $/Acre Construction Period			Sediment Damages To Stream $/Acre	Residual Value $/Acre	Grand Total $/Acre/ Construction Period
	Seed & Fertilizer	Straw Mulch	Chemical System: Straw Tack	Chemical System: X			Normal	With Flocculant			Structures & Basins	Engineering	Surface Stabilization	Rounded Total	Sediment Basin	Erosion Damage & Restoration	Total			
10	▒	▒			▨	▤				91	421	55	500	975	50	100	150	140	-100	1,165
17				▒	▨	▤				84	421	55	300	775	80	150	230	215	–	1,220
18	▒			▒	▨	▤				90	421	55	480	955	55	100	155	145	-100	1,155
19	▒	▒	▒		▨	▤				91	421	55	493	970	50	100	150	140	-100	1,160
40	▒	▒					●			93	108	21	500	630	220	200	420	185	-225	1,010
41	▒						●			87	108	21	209	340	360	250	610	340	-225	1,065
42				▒			●			87	108	21	300	430	320	250	570	295	-125	1,170
43	▒			▒			●			92	108	21	480	610	235	200	435	200	-225	1,020
50	▒	▒						●		96	185	21	500	705	245	200	445	140	-235	1,055
51	▒							●		94	185	21	209	415	400	250	650	250	-235	1,080
52				▒				●		94	185	21	300	505	360	250	610	220	-135	1,200
53	▒			▒				●		96	185	21	480	685	260	200	460	150	-235	1,060
60	▒	▒			▨	▤			░	93	421	55	500	(see text)	40	100	140	100	-100	N.E.
61	▒	▒						●	░	97	185	21	500	(see text)	200	200	400	105	-235	N.E.
70	Natural Terrain Building									(see text)	–	–	–	N.E.	–	–	N.E.	–	–	N.E.
80	▒	▒			▨	▤	(with spot building)			(see text)	–	–	–	N.E.	–	–	N.E.	–	–	N.E.

Exhibit 263. COST AND EFFECTIVENESS OF MOST PROMISING CONTROL SYSTEMS

			Costs, $/Acre		
System Number	Components	% Effec-tiveness	Treatment* Maintenance -Residual	Stream Damage	Total
10	Seed, fertilizer, straw mulch. Erosion structures (normal). Sediment basins (.04/acre).	91	1,025	130* 140*	1,155 1,165
18	Same as (10) except chemical X replaces straw mulch.	90	1,010	145	1,155
19	Same as (10) except chemical straw tack replaces asphalt.	91	1,020	140	1,160
20	Seed, fertilizer, straw mulch. Diversion berms. Sediment basins (.06/acre).	90	1,010	145*	1,155
40	Seed, fertilizer, straw mulch. Downstream sediment basin.	93	825	185	1,010
43	Seed, fertilizer, chemical X. Downstream sediment basin.	92	820	200	1,020
50	Seed, fertilizer, straw mulch. Downstream sediment basin using flocculants.	96	915	140	1,055
51	Same as (50) without straw mulch.	94	830	250	1,080
52	Chemical X. Downstream sediment basin using flocculants.	94	1,080	220	1,200
53	Same as (52) with seed, fertilizer.	96	910	150	1,060

* Stream damage costs for System 1 are $130 and $140/acre for Gaithersburg and Germantown segments respectively. The difference is due to the higher delivery ratio used for the Germantown segment to calculate sediment damage costs in Section IX.

** Sediment damage cost would be a few dollars higher if this system had been imposed on Germantown segment.

APPENDIX G: REFERENCES FOR APPENDICES A THROUGH F

A-1 Andreluinas, V. L., "Real or Imaginery Dilemna?," Water Spectrum, Vol. 4, No. 1 (1972).

A-2 Arthur D. Little, Inc., Report on Channel Modifications, Council on Environmental Quality, Washington, D.C. (1973).

A-3 Barnett, A. P., and et al, "Evaluation of Mulching Methods for Erosion Control on Newly Prepared and Seeded Highway Backslopes," Agronomy Journal, Vol. 59, pp 83-85 (1967).

A-4 Becker, B. C., Mills, T. R., and Maryland Department of Water Resources, Guideline for Erosion and Sediment Control Planning and Implementations, Hittman Associates, Inc., for Maryland Department of Water Resources and the U.S.E.P.A., Washington, D. C.

A-5 Bethlahmy, N., and Kidd, W. J. Jr., Controlling Soil Movement from Steep Roadfills, Boise, Idaho, U. S. Forest Service Research Note INT-45, USDA, Inter-Mountain Forest and Range Experiment Station (1966).

A-6 Bobb, W. H., and et al, Effects of a Proposed 35 ft Channel to Richmond on the Currents and Salinities Over the Seed Oyster Beds in James River, U. S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Miss., (September 1966).

A-7 Brandt, Gerald H., et al, An Economic Analysis of Erosion and Sediment Control Methods for Watersheds Undergoing Undergoing Urbanization, W72-08246, The Dow Chemical Co., Midland, Michigan, 191P, PB-209-212 (February 1972).

A-8 Brown and Caldwell Inc., "Effects of Dredged Materials on Dissolved Oxygen in Receiving Water," U. S. Army Corps of Engineers, San Francisco District (March 1973).

A-9 Churchill, Constance L., et al, Effect of Dredging on the Nutrient Levels and Biological Populations of a Lake, W73 00938, South Dakota State University, Brookings Water Resources Institute, 164P, PB-212-718 (August 1972).

A-10 Cox, A. L., et al, "Erosion Control Study, Part II - Roadside Channels," Highway Research Report, U. S. Department of Transportation, Federal Highway Administration (April 1971).

A-11 Coyote Creek and Cold Creek Sediment Studies near South Lake Tahoe, California. Unpublished information obtained through internal communication with (1) California Regional Water Resources Control Board (Lahontan Region), and (2) Department of Plans and Permits, South Lake Tahoe, California.

A-12 Crawford, N. H., and Donigan, A. Jr., Pesticide Transport and Runoff Model for Agricultural Lands, Hydrocomp, Inc., EPA 660/2-74-13, (Prepublication copy) (December 1973).

A-13 Diseker, E. G., and Richardson, E. C., "Control of Roadbank Erosion in the Southern Piedmont," Agronomy Journal, Vol. 53, pp 292-294 (1961).

A-14 Diseker, E. G., and Richardson, E. C., "Erosion Rates and Control Methods on Highway Cuts," Transactions of the ASAE, Vol. 5, pp 152-155 (1962).

A-15 Diseker, E. G., and Richardson, E. C., "Roadside Sediment Production and Control," Transactions of the ASAE, Vol. 4, pp 62-68 (1961).

A-16 Elder, R. A., et al, "Proceedings of the Specialty Conference on Current Research into the Effects of Reservoirs on Water Quality," Technical Report No. 17, Department of Environmental and Water Resource Engineering, Vanderbilt University, pp 1-50 (January 1968).

A-17 Emerson, J. W., "Channelization: A Case Study," Science, Vol. 173, pp 325-326 (July 1971).

A-18 Fairfax County (Virginia) Erosion-Siltation Control Handbook, Fairfax, Virginia (December 1973).

A-19 Guy, H. P., "Residential Construction and Sedimentation at Kensington, Maryland," Proceedings of Federal Inter-Agency Conference, 1963, Miscellaneous Publication No. 920, USDA, Agricultural Research Service (June 1965).

A-20 Guy, H. P., and Clayton, I. L., "Some Sediment Aspects of Tropical Storm Agnes," Journal of the Hydraulics Division, ASCE, Vol. 99, No. HY9, p 1653 (1973)

A-21 Guy, H. P., and Ferguson, G. E., "Sediment in Small Reservoirs Due to Urbanization," Journal of the Hydraulic Division, American Society of Civil Engineers (March 1962).

A-22 Hammer, T. R., "Stream Channel Enlargement Due to Urbanization," Water Resources Research, Vol. 8, No. 6 (December 1972).

A-23 Hendrikson, B. H., "A Fertility Survey of Exposed Subsoils from Highway Road Banks in the Coosa Watershed of Northwest Georgia," Journal of Soil and Water Conservation, Vol. 13, No. 1 (January 1958).

A-24 Hendrickson, B. H., "A Fertility Survey of Exposed Subsoils from Highway Roadbanks in the Coosa Watershed of Northwest Georgia", Journal of Soil and Water Conservation, Vol. 27, No. 6, p 264 (November - December 1972).

A-25 Hittman Associates Inc., Demonstration of the Separation and Disposal of Concentrated Sediments, Prince George's Co., Maryland, USEPA, Washington, D.C. (February 1974).

A-26 Hittman Associates, Inc., Joint Construction Sediment Control Project, Columbia, Maryland, USEPA, Office of Research and Development, Washington, D. C. (June 1973).

A-27 Holeman, J. N., Sedimentation of Loch Raven and Prettyboy Reservoirs, Baltimore Co., Maryland, SCS-TP-145, USDA Soil Conservation Service (February 1965).

A-28 Holeman, J. N., and Geiger, A. F., "Sedimentation of Lake Barcroft Fairfax County, Va.," SCS-TP-136, Soil Conservation Service, USDA, Washington, D. C. (March 1959).

A-29 Hotes, F. L., et al, Comparative Costs of Erosion and Sediment Control for Construction Activities, EPA-430-9-73-016, Engineering-Science, Inc., for U.S.E.P.A., Office of Water Program Operations, Washington, D. C. (July 1973).

A-30 Jeane, G. S., and Pine, R. E., Hydraulic Dredging and the Effect of a Method of Spoil Disposal on Water Quality and Juvenile Salmon Survival in Port Gardner, Everett, Washington, Department of Ecology, Washington State University (February 1973).

A-31 Klehr, E. H., Behavior of Water in a Southwestern Impoundment - Lake Thunderbird, A-013-OKLA, School of Civil Engineering and Environmental Science, University of Oklahoma, Norman, Oklahoma.

A-32 Knott, J. M., "Effects of Urbanization on Sedimentation and Flood Flows in Colma Creek Basin, California," Open File Report, U.S. Geological Survey, Menlo Park, California (February 1973).

A-33 Krizek, R. J., et al, "Engineering Characteristics of Polluted Dredging," U.S.E.P.A., Washington, D. C. (March 1973).

A-34 Kroll, C. G., Sediment Discharge in the Lake Tahoe Basin, California: 1972 Water Year, USDI Geological Survey, Water Resources Division, Menlo Park, Calif. (1973).

A-35 McCaw, W. J., Water Quality of Montgomery County Streams and Sewage Treatment Plant Effluents December 1969 - January 1974, Montgomery County, Maryland, Division of Environmental Protection, Rockville, Maryland (August 1974).

A-36 Meyer, L. D., et al, "Stone and Woodchip Mulches for Erosion Construction Sites," Journal of Soil and Water Conservation, Vol. 27, No. 6, p 264 (November - December 1972).

A-37 Meyer, L. D., et al, "Mulch Rates Required for Erosion Control on Steep Slopes," Soil Science Society of America Proceedings, Vol. 34, No. 6, pp 928-931 (November - December 1970).

A-38 Pacific Northwest Laboratories, Battelle Memorial Inst., Characterization of Pollutant Availability for San Francisco Bay Dredge Sediments, U. S. Army Corps of Engineers, San Francisco District (January 1974).

A-39 Reed, L. A., Effects of Roadway and Pond Construction of Sediment Yield Near Harrisburg, Pennsylvania, Open File Report, U. S. Geological Survey, Harrisburg, Pa. (August 1971).

A-40 Reed, L. A., et al., Progress Reports No. 17 (Jan. 1, 1973 - March 31, 1973), and No. 21 (January 1, 1974 - March 1974), on Renach Project No. 68-34, "Evaluation of Erosion Control Measures Used in Highway Construction," U.S. Geological Survey, Water Resources Division, Harrisburg, Pa.

A-41 Reeder, H. F., Sediment Resulting from Construction of Interstate Highway I-40 in North Carolina, USDI, Geological Survey, Raleigh, North Carolina.

A-42 Roehl, J. W., "Sediment Source Areas, Delivery Ratio and Influencing Morphological Factors," International Union of Geodesy and Geophysics, International Association, Scientific Hydrology, Pub. No. 59, pp 202-213 (1962).

A-43 Roth, C. P., et al, Prediction of Subsoil Erodibility Using Chemical, Mineralogical and Physical Parameters, (Contract No. 6709, Project No. 15030, HIX), National Environmental Research Center, Cincinnati, Ohio (December 1973).

A-44 Ruhe, R. V., "Stream Regimen and Man's Manipulation," Environmental Geomorphology, Coates Publishing Co., (1970).

A-45 Sciandrone, J. C., "Environmental Protection at a California Dam," Civil Engineering, ASCE, pp 80-83 (March 1974).

A-46(a) Schmidt, J. H., and Summers, A. W., "The Effects of Urbanization on Sedimentation in the Clinton River Watershed," Unpublished Thesis, University of Michigan, Ann Arbor (1967).

A-46(b) Servizi, J. A., et al., "Marine Disposal of Sediment, from Bellingham Harbor as Related to Sockeye and Pink Salmon Fisheries," Program Report No. 23 International Pacific Salmon Fisheries Commission, New Westminister B.C. (1969).

A-47 "Shorter Papers and Notes: Detrimental Effects of Highway Construction on a Montana Stream," Transactions of the American Fisheries Society, Vol. 88, pp 72-73 (1959).

A-48 Swerdon, P. M., and Kountz, S. R., Sediment Runoff Control at Highway Construction Sites, Engineering Research Bulletin B108, The Pennsylvania State University, College of Engineering, University Park, Pa. (January 1973).

A-49 Thompson, J. R., "Soil Erosion in the Detroit Metropolitan Area," Journal of Soil and Water Conservation, Vol. 25, No. 1 (January - February 1970).

A-50 U. S. Army Corps of Engineers, "Dredge Materials Research," ODMR, Misc. Paper D-73-3 (July 1973).

A-51 U. S. Army Corps of Engineers, "Dredge Spoils Disposal Monitoring San Pablo Bay: February 5, 1974," Corps of Engineers San Francisco District (March 1974).

A-52 U. S. Department of Agriculture, Protecting Steep Construction Slopes Against Water Erosion, Progress Report 2, Soil and Water Conservation Research Division, Lincoln, Nebraska (September 1967).

A-53 U. S. Geological Survey, "Evaluation of Erosion Control Measures Used in Highway Construction," Undated Project Summary, Received by MITRE from U.S.G.S., Harrisburg, Pa.

A-54 Vice, R. B., et al, Sediment Movement in an Area of Suburban Highway Construction, Scott Run Basin, Fairfax Co., Virginia, 1961-1964, Hydrologic Effects of Urban Growth, U. S. Geological Survey, p 1591-E (1973).

A-55 Wolman, M. G., "Problems Posed by Sediment Derived from Construction Activities in Maryland," Report to Maryland Water Pollution Control Commission, Annapolis, Md., p 125 (January 1964).

A-56 Wolman, M. G., and Schick, A. P., Effects of Construction of Fluvial Sediment in Urban and Suburban Areas of Maryland, Water Resources Research, Vol. 3, No. 2 (1967).

A-57 Yorke, T. H., and Davis, W. J., Sediment Yields of Urban Construction Sources, Montgomery Co., Maryland, USDI, Geological Survey, Rockville, Maryland (1972).

APPENDIX H: LIST OF PERSONAL COMMUNICATIONS

(all Dates are in 1974)
(T-telephone, V-visit, L-leter)

Alabama State Highway Department		
Mr. C. A. Bowles, Construction Engineer	T	
Arizona Highway Department		
Mr. Sandlin, Assistant State Engineer in Construction	T	
Arkansas State Highway Department		
Mr. Steve Wilson, Environmental Development Office	T	
California Division of Highways		
a. Mr. Roy Chalmers	T	
b. Mr. Roy Forsyth, Chief Foundation Section	T	
c. Mr. John Skog, Head, Physical Environmental Section, Transportation Lab., Sacramento	T	Apr. 30
California Water Quality Control Board		
a. Mr. John Baker, Sanitary Engineering Specialist, Lahontan Region	V	May 8
b. Mr. Alvin Franks, Supervising Engineering Geologist	V	May 7
Connecticut Department of Transportation		
Mr. James Spencer, Chief, Hydraulics and Drainage Section	T	
Delaware Department of Highways and Transportation		
a. Office of the Director of Highways	T	
b. Department of Resources and Controls	T	
Dow Chemical Company		
Mr. M. B. Ettinger, Pollution Specialist	T	July 9
Fairfax County, Virginia		
a. Mr. William W. Smith, Jr., Division of Design Review	V	May 1
b. Mr. Don Koeing, Bonding Coordination	V	May 1
Florida Department of Transportation		
Mr. Grover Rivers, Office of Road Operations	T	

Georgia Department of Transportation		
Mr. Paul Stimke, Planning Office	T	
Illinois Department of Transportation		
Mr. George Rose, Bureau of Environmental Science	T	
Kansas State Highway Commission		
Mr. John McNeal, State Highway Engineer	T	
Kentucky Department of Transportation		
Mr. Phillip Booker, Roadside Development	T	
Louisiana Department of Highways		
a. Mr. George Landry, Environmental Engineer	T	
b. Mr. Joe Tumey, Specifications Section	T	
Maine Department of Transportation		
Mr. Bill Reid, Bureau of Planning	T	
Maryland Water Resources Administration		
a. Mr. Ward Brenner, Sedimentation Specialist	T	Mar. 21
b. Mr. Michael Ports, Civil Engineer Surface Water Division	V	Mar. 29
Massachusetts Department of Public Works		
Mr. Robert Horigan	T	
Michigan Department of State Highways		
Mr. Tom Coleman, Soil Division	T	
Minnesota Department of Highways		
Mr. Stanley Ekern	T	
Missouri State Highway Commission		
Mr. Breuer, Construction Department	T	
Mississippi State Highway Department		
Mr. Jesse Whitten, Environmental Section	T	
Montana Department of Highways		
Mr. Bahls, Environmental Quality Office	T	
Nebraska Department of Roads		
Mr. Dick Webb, Environmental Studies		
New Hampshire Department of Public Works and Highways		
Mr. Robert Dowst, Special Services	T	

New Jersey Department of Transportation		
Mr. William Davis, Soils Specialist	T	
New Mexico State Highway Department		
Mr. Harley Parr, Hydraulic Engineer	T	
New York State Department of Transportation		
Mr. Hofmann, Technical Services	T	
North Carolina Department of Transportation and Highway Safety		
Mr. Bowen, Landscape Department	T	
North Dakota State Highway Department		
Mr. Charles Gullicks, Environmental Group	T	
Ohio Department of Transportation		
Mr. Robert Allen, Environmental Studies Group	T	
Oregon Department of Transportation		
a. Mr. Gary Potter, Environmental Department	T	
b. Ms. Priscilla Harney, Environmental Department	T	
Pennsylvania Department of Transportation		
Mr. William G. Weber, Research Engineer, Bureau of Materials, Testing and Research	V	Apr. 16
South Dakota Department of Transportation		
Mr. Windal Andrews, Roadside Development	T	
Tennessee Department of Transportation		
Mr. Ben Smith, Environmental Section	T	
Tennessee Valley Authority		
Mr. Roger Betson, Head, Hydrologic Research	T	July 16
and Analysis Section	T	July 18
Texas Highway Department		
Mr. R. L. Lewis, Chief Engineer of Highways Design	T	
U. S. Agricultural Research Service		
a. Mr. A. P. Barnett, Coosa Watershed Research Project, Watkinsville, Georgia	T	Apr. 19
b. Dr. Harold Barrows, National Programs Office, Washington, D.C.	V	Apr. 20

U. S. Agricultural Research Service (continued)

c.	Mr. J. B. Borford, Hydrologic Data Lab, Beltsville, Md.	V	Apr. 23
d.	Mr. Andy Bowie, Sediment Yield Group, USDA Sedimentation Lab, Oxford, Miss.	V	Apr. 23
e.	Dr. Earl H. Grissinger, Sediment Properties Group, USDA Sedimentation Lab, Oxford, Miss	V	Apr. 24
f.	Dr. W. Campbell Little, Stream Stabiliz[illegible] Group, USDA Sedimentation Lab, Oxford, [illegible]	V	Apr. 24
g.	Dr. Jesse Lunin, Sedimentation Branch Beltsville, Md.	T	Mar. 22
h.	Dr. L. Donald Meyer, Soils Specialist USDA Sedimentation, Oxford, Miss.	V	Apr. 23
i.	Dr. Calvin K. Mutchler, Sediment Yield Group USDA Sedimentation Lab, Oxford, Miss.	V	Apr. 23
j.	Dr. M.J.M. Römkens, Soil Physicist USDA Sedimentation Lab, Oxford, Miss.	V	Apr. 23

U. S. Army Corps of Engineers

a.	Capt. William Allanach, Office of Dredged Material and Research, Waterways Expt. Station, Vicksburg	V	Apr. 24
b.	Dr. Robert M. Engler, Research Soil Scientist, Waterways Expt. Station	V	Apr. 25
c.	Mr. J. L. Grace, Jr., Chief, Structures Group, Hydraulics Br., Waterways Expt. Station, Vicksburg	V	Apr. 25
d.	Major F. H. Griffis, Jr., ODMR, Waterways Expt. Station, Vicksburg, Miss.	V	Apr. 25
e.	Capt. Robert Meccia, District Coordinator, ODMR, Waterways Expt. Station, Vicksburg	V	Apr. 25
f.	Mr. Stafford, Construction Branch, Vicksburg District Office	T	Apr. 25
g.	Mr. Thomas Wakeman, San Francisco District	V	May 5

U. S. Bureau of Reclamation

a.	Mr. E. J. Carlson, Hydraulics Branch	V	May 6
	Denver Federal Center	V	May 14
b.	Dr. John C. Peters, Environmental Specialist Denver Federal Center	V	May 6

U. S. Department of Housing and Urban Development

	Mr. D. Earl Jones, Jr., Environmental and Land Use Division, Hq., Washington, D.C.	V	Mar. 29

U. S. Department of Transportation

a.	Dr. Mylo D. Cress, Implementation Manager, Washington, D.C.	V	Apr. 8

U. S. Department of Transportation (continued)

b.	Dr. Byron Lord, Environmental Engineer Environmental Design and Control Division, Washington, D.C.	V	Apr. 8
c.	Mr. Douglas McTavish, Highway Engineer Highway Systems Branch, Washington, D.C.	T	
d.	Mr. Douglas Smith, Environmental Design and Control Division, Washington, D.C.	V	Apr. 8

U. S. Environmental Protection Agency

a.	Dr. George Bailey, Soil Physical Chemist Southeastern Environmental Research Lab	T	Apr. 4 Apr. 19
b.	Mr. Kenneth Feigner, Seattle Regional Office	T	Apr. 19
c.	Mr. Fred Hoffman, Non-Point Source Division San Francisco Regional Office	T	Apr. 30
d.	Mr. Will C. LaVeille, Non-Point Pollution Control Div. Hq., Washington, D.C.	V	Mar. 20
e.	Mr. J. J. Mulhern, Mining Engineer, Hq., Washington, D.C.		
f.	Mr. Bruce Perry, Non-Point Source Division	V	May 6
g.	Mr. John Riley, Denver Region, Effluent Guidelines Division, Hq., Washinton, D,C.	T	May 29
h.	Mr. Robert Thronsin, Office of Water Programs Hq., Washington, D.C.	V	Mar. 21
i.	Mr. John Weiss, San Francisco Regional Office	T	Apr. 29

U. S. Forest Service

a.	Dr. Ted Dyrness, Forest Science Laboratory Corvallis, Oregon	V	May 9
b.	Mr. Ed Johnson, Watershed Management, Washington, D.C.	V	Mar. 27
c.	Dr. J. Sam Krammes, Div. of Forest Environmental Research, Washington, D.C.	V	Mar. 27
d.	Mr. Ralph Maloney, Water Yield Management, Washington, D,C,	V.	Mar. 27
e.	Dr. Paul Packer, Forestry Science Laboratory Utah State University, Logan	V	May 13
f.	Dr. Douglas N. Swantson, Forestry Sciences Lab, Oregon State Univ., Corvallis	V	May 9

U. S. Geological Survey

a.	Dr. Harold P. Guy, Research Hydrologist, Reston, Va.	V	May 1
b.	Mr. James M. Knott, Hydrologist Water Resources Division, Menlo Park, Calif.	T L	May 2 May 3
c.	Dr. Thomas Maddock, Jr., Sedimentation Specialist, Reston, Va.	L V	Jan. 25 Mar. 13
d.	Mr. Lloyd Reed, Project Chief, Harrisburg, Pa.	V	

U. S. Office of Water Resources Research		
Mr. Herbert A. Swenson	T	July 9
U. S. Soil Conservation Service		
a. Mr. R.C. Barnes, Engineering Division	V	Apr. 2
b. Mr. John N. Holeman, Engineering Division	V	Apr. 2
c. Mr. Henry H. Williamson, District Conservationist, Fairfax, Va.	V	Mar.
Utah Water Research Laboratory (Utah State University, Logan)		
a. Dr. Calvin G. Clyde	V	May 13
b. Dr. Earl Israelson	V	May 13
Vermont Department of Highways		
Mr. Schribner, Assistant to the Chief Engineer	T	
Virginia Department of Highways		
Mr. William Clemis, Environmental Quality Engineer	T	
Washington State Department of Ecology		
Mr. John R. Raymond, Water Investigations Division	V	May 10
Washington State Department of Highways		
a. Mr. Charles Gosney, Construction Engineer	V	May 10
b. Mr. Herbert W. Humphres, Chief Construction Engineer	V	May 10
c. Mr. Warren Imus, Specifications Engineer		
West Virginia Department of Highways		
Mr. Joseph Jones	T	
Wisconsin Department of Transportation		
Mr. Aten, Construction Section	T	
World Dredging Conference, San Pedro. Calif.		
a. Mr. Arve Arresen	T	Apr. 29
b. Mrs. Hogar, Editor, World Dredging and Marine Construction	T	Apr. 29
Wyoming Highway Department		
Mr. Bastrom, Environmental Services	T	

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